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VOLUME XXXVII.

EDITED BY GEORGE HOLMES,

SECRETARY OF THE INSTITUTION.

1896.

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Shotton, J. W.
Sibbick, C.
Sibun, James
Sigaudy, P.
Simey, George H. T.
Simons, William
Simpson, Francis C.
Simpson, George
Sinclair, Russel
Skinner, James
Smith, C. E.
Smith, John
Smith, Wasteneys
Smith, W. E.
Soliani, Nabor, Colonel Royal Italian Navy
Soper, Joseph M.
Soper, Thomas (Mem. Council)
Spear, John
Spears, F. P.
Spence, Henry Grant
Spence, J. C.
Spyer, Arthur
Stahl, Albert W.
Stainer, George Henry
Stanbury, George (Mem. Council)
Steele, Robert
Steele, W. R.
Stephen, A.
Stephen, F. J.
Stephenson, F.
Stewart, Alexander
Stewart, James
Stewart, John
Stoddart, John E.
Stone, Douglas
Stoney, Bindon Blood
Storey, W. C.
Stratton, E. Platt
Stromeyer, C. E.
Strong, George H.
Stuelcken, J. C.
Summers, William
Swainston, W. H.
Swan, Henry Frederick
Syme, James

Tagg, Thomas G.
Tatham, Stanley
Taylor, Alexander
Taylor, Benson
Taylor, D. W., U.S.N.
Taylor, John
Taylor, Peter
Tennyson-d'Eyncourt, E. H.
Thayer, I. E.
Thearle, Samuel J. P.
Thom, John
Thompson, John Augustus
Thompson, J. E.
Thompson, J. L.
Thompson, Robert
Thompson, W. B.
Thomson, Archibald
Thomson, Charles
Thomson, G. Paul
Thomson, J. Rodger (Mem. Council)
Thomson, James, M.A.
Thomson, J. M.
Thomson, R. H. B.
Thornycroft, J. I., F.R.S. (Vice-President)
Tierney, Edward J.
Timme, George A.
Tobin, J. A.
Todd, Thomas
Tower, Beauchamp
Trewent, Francis J.
Tritton, Seymour B.
Turk, Gerbrand
Turnbull, Thomas
Turpin, James
Tuxen, I. E., Captain, R.D.N.
Tweedy, John

Valsecchi, Capt. Giuseppe, Royal Italian Navy
Viehoff, Jacobus M.
Vivet, Léon
Von Kodolitsch, F.
Voss, E. C. A.

Wadia, Bomanjee S.
Walker, George
Walker, John
Wallace, William
Wallace, W. Carlile
Walpole, Thomas
Walter, C. O. M.
Ward, John
Warder, G. E. E.
Warner, Saul
Warren, Ruben H.
Warren, T. Samuel
Watkins, Alfred
Watkins, William
Watson, George Lennox
Watson, Ralph
Watson, William
Watts, Philip (Mem. Council)
Weeks, Courtenay O.
Weighton, Robert L.
Weir, James
Welch, John Joseph
Welsh, T. M.
Wemyss, J. Leith
West, Henry H. (Mem. Council)

Westgarth, Tom
Westmacott, A.
Westwood, J., jun.
Wheatley, W. C.
White, John S.
White, R. Saxton
White, Sir William Henry, K.C.B., LL.D., F.R.S. (Vice-President)
Whiting, William H.
Whyte, William
Widdas, Tom Dodd
Widmann, Daniel E.
Wildish, James George
Wilkins, J. Edwin
Wilkinson, Henri
Williams, Jesse
Williamson, James
Williamson, Robert
Wilson, Alexander Hall
Wilson, J. P.
Wilson, Walter Henry
Wiltshire, George
Wimshurst, J. E.
Winstanley, P. D.
Withy, Henry
Wolff, Gustav W., M.P.
Woods, Arthur R. T.
Woodward, J. J.
Workman, Frank
Wotherspoon, John H.
Wright, Sir James, C.B. (Vice-President)
Wright, J. J.

Yamaki, Gonzaburo
Yarrow, A. F. (Vice-President)
Yates, James A.
Yeo, John
Young, J. Denholm
Young, Sidney
Young, W. Andrew
Younger, Archibald Scott, B.Sc.

Zeysing, Theodore, Imperial German Navy
Ziese, Carl H.
Zimmermann, Robert

Associates.

Acland, W. A. D., Captain, R.N.
Adams, A. C.
Agius, Edgar
Agius, E. T.
Ailsa, The Most Hon. the Marquis of
Alliman, Albert
Amsler, Alfred, Dr.
Angier, Captain T. V. S.
Armstrong, The Right Hon. Lord, C.B., D.C.L., F.R.S. (Vice-Pres.)
Armstrong, F. H., Colonel
Arnold, W. T. A.
Atkins, H. S.
Attridge, J. W.
Aukland, Thomas F.
Aynsley, C. Murray, C.B., Rear-Admiral, R.N.

Baker, Lieut.-Col. R. Barrington
Bains, G. S. L.
Bankson, Lloyd
Barnett, Samson
Barnwell, R.
Barraza, M., Capt. Argentine Navy
Barreto, Baron
Barrie, Charles
Baxter, W. J., U.S.N.
Bayford, J. J.
Beardmore, William
Becher, S. J.
Beldam, Robert
Bell, Jas.
Bennett, T. J.
Beresford, Captain the Right Hon. Lord Charles, C.B., R.N.
Billinton, R. J.
Blackmore, Edward
Blundstone, Samuel R.
Bowden-Smith, Vice-Admiral N., R.N.
Boys, Henry, Admiral
Bramwell, Sir Frederick, Bart., D.C.L., F.R.S. (Vice-President)
Brand, J. Arthur
Brassey, the Right Hon. Lord, K.C.B. (Past President)
Brassey, The Hon. Thomas A.
Brereton, C. A.
Brown, A. H.
Brown, Joseph
Brunel, H. Marc
Bryant, Henry
Bullivant, W. P.

Cameron, Nelson
Caminos, Jacinto Z., Lieutenant, Argentine Navy
Campbell-Thompson, J.
Canter, William James, R.N.
Carttar, Edward Arundel
Cay, Matthew
Chadburn, A. W.
Chapman, Henry
Chapman, Walter
Chatfield, Alfred J., Admiral, C.B.
Chubb, Richard
Church, E. J., Rear-Admiral
Churchill, James D.
Clark, John
Clark, John A.
Clark, Lyonel E.
Cleghorn, Alexander
Cleveland, H. F., Rear-Admiral
Cobb, George H.
Cohan, E. A.
Cohen, Arthur, Q.C.
Cohn, A.
Collin, D.
Collis, T. J.
Colomb, P. H., Vice-Admiral, R.N.
Commerell, Admiral of the Fleet Sir J. E., G.C.B., V.C.
Cookes, T. S.
Cooper, J. H., Colonel
Corry, John (Assoc. Mem. Council)
Cotterill, Professor J. H., M.A., F.R.S. (Assoc. Mem. Council)

Cowles, W. Sheffield, Lieut.-Com., U.S. Naval Attaché
Craddock, T. F.
Crease, John Frederick, Maj.-Gen., R.M.A., C.B.
Crofton, Edward
Cross, William
Crow, A. H.
Crowder, T. W., Capt.
Custance, Reginald, Capt. R.N.

Da Costa, S. J.
Darling, John
De Cuverville, J. De Cavelier, Le Vice-Amiral, French Navy
De Horsey, Algernon F.R., Admiral
De Salis, H. R.
Dempster, John
Denny, John M., M.P.
Depree, A. O.
Devine, W. H.
Dickinson, C. F.
Dixon, H. Raylton
Dixon, James
Dodd, J. B.
Domoney, J. W.
Donaldson, William A.
Donkin, Richard Sims, M.P.
Dove, E. J.
Dryhurst, A. G.

Eckart, William R., C.E.
Eidlitz, Leopold, jun.
Ellis, Chas. Ed.
Ellis, W. H. M.
Elmslie, Major F. B.
Emory, W. H., Captain, U.S.N.
Epes, H. S.
Etheridge, C. K.
Etherington, John A. E.
Evans, David
Evans, Frederick R.

Fairfax, Joseph S.
Fanshawe, Sir Edward Gennys, G.C.B., Admiral
Fenwick, J. Fenwick
Ferguson, H. L.
FitzGerald, C. C. P., Rear-Admiral, R.N.
Fitzgerald, D. W.
Flemmich, G. F.
Foster, J. W.
Fowler, Sir John, K.C.M.G., F.R.S., Bart.
Fox, Samson
Fradgley, J. B.
Fraissinet, Alfred
Fremantle, Vice-Admiral The Hon. Sir E. R., K.C.B., C.M.G.
Froud, A. G.
Froude, R. E., F.R.S. (Assoc. Mem. Council)

Garcia, D. C., Lieut. Argentine Navy
Gardner, P.
Garrett, S.
Gervais, A., Admiral, French Navy
Gilchrist, Percy C.
Glenfield, F.
Gough, Kedgwin E. K.
Grainger, Thomas L.
Graves, W. T.
Green, R. H.
Green, W. Miall
Gross, Felix
Gülich, E., Captain, I. German Naval Attaché
Guppy, Thos. R.

Hadfield, R. A.
Hamilton, The Right Hon. Lord George, M.P. (Vice-President)
Hamilton, W. Des Vœux, Captain R.N.
Harfield, William Horatio
Harper, G. T.
Hartmann, August
Hartmann, G.
Hartmann, Wilhelm
Hay, James M.
Hay, The Right Hon. Lord John, G.C.B., Admiral of the Fleet (Vice-President)
Hay, The Right Hon. Sir John Dalrymple, Bart., K.C.B., D.C.L., F.R.S., Admiral (Vice-President)
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Healey, Edward C.
Henderson, George T.
Hepworth, M. W. C.
Hibbs, F. W.
Hick, Thomas
Hill, E. J.
Hill, Sir E. S., Colonel, K.C.B., M.P.
Hills, Arnold F.
Hodges, Petronius
Hodgkinson, George
Hodd, Thos. H.
Hogarth, A. P.
Holland, Arthur, M.A.
Holland, S. C., Captain, R.N.
Holzapfel, A. C. A.
Holzapfel, Max
Hope, L. C.
Hopetoun, The Right Hon. the Earl of, G.C.M.G. (President)
Hopkins, Sir John Ommaney, Vice-Admiral, K.C.B.
Houlder, A. F.
Houldsworth, William
Howard, J. William
Howell, J. Bennett
Hoyle, J. Rossiter
Hozier, H. M., Colonel
Huddart, James
Hume, W. C.
Hurndall, W. F.
Hutchinson, Walter E.

Ihlen, Nils, Admiral, Royal Norwegian Navy
Ismay, J. Bruce
Ismay, Thomas H. (Assoc. Mem. Council)
Ivanoff, N., Lieut.-Col., Imperial Russian Navy

Jack, Thomas
Jackson, J. E.
Japp, John
Jaques, Capt. W. H., late United States Navy
Jarman, Stephen, R.N.R.
Jedina, The Chevalier L. de, Captain, I. and R. Austro-Hungarian Naval Attaché

Johnson, Arthur
Johnstone, Lieut. George, R.N.R.
Jullien, M.

Kemp, Dixon
Kettelwell, A. S.
King, Percy Liston
Kirkaldy, John
Kirkaldy, Thomas
Knott, James
Knudson, Gunnar
Kriloff, Captain A. N., Imperial Russian Navy
Kröller, A. G.

Laeisz, C. Ferd.
Lagerwall, J. M., Captain, Royal Swedish Navy
Lambert, Professor Carlton J.
Lambton, Captain the Hon. Hedworth
Latorre, Juan José, Rear-Admiral Chilian Navy
Laws, George A.
Laws, G. Umfreville
Le Doux, Richard
Leflaive, L. J. G.
Lewes, Professor Vivian B., F.I.C., F.C.S. (Assoc. Mem. Council)
Likhatchof, J., Vice-Admiral, Imperial Russian Navy
Linley, Joseph A.
Lister, W. N., Lieut., R.N.R.
Little, Henry W.
Littleboy, C. W.
Lloyd, Com. E. W., R.N.
Lloyd, R. Samuel
Long, A. E.
Lund, William
Lyell, F. H.

MacDonnell, Alexander
MacDougall, Dugald
MacIlwraith, A.
Mackay, Sir J. L., K.C.I.E.
Marr, James
Marshall, Frank T.
Martin, E. P.
Martin, W. Tyson
Martino, The Chevalier Eduardo de
Massey, W. A.
McCalmont, H. L. B., M.P.
McGregor, J.
McGregor, Allan Gow
McIntyre, John
Meehan, H.
Metcalfe, John
Meyer, John
Milburn, J. D.
Miller, Gordon
Milne, Sir Alexander, Bart., G.C.B., Admiral of the Fleet (Vice-President)
Montero, N.
Montgomery-Moore, A. W.
Moore, W. J. P.
Morant, George Digby, Vice-Admiral (Assoc. Mem. Council)
Morrison, James
Mullan, F. C.

Napier, James
Neal, William George
Neilson, John
Nelson, T. H.
Newey, Capt. Samuel C.
Newman, A. R.
Nicholl, E.
Nicolson, Sir Frederick W. E., Bart., C.B., Admiral (Vice-President)
Niven, O. B., Com.
Niven, W. D., F.R.S.
Noad, Lewis.
Noel, G. H., Rear-Admiral (Assoc. Mem. Council)
Northbrook, The Right Hon. the Earl, G.C.S.I. (Vice-President)

O'Connor, C.
Oukhtomsky, Prince P., Imperial Russian Naval Attaché

Panton, Charles E.
Park, J. Smith
Parker, J. Henry
Parsons, P. R.
Pascoe, J. R.
Pearce, Sir William G., Bart., M.A., LL.B.
Perkins, James
Petersen, Otto L.
Petersen, William
Pharo, Jacob C.
Pilcher, Percy S.
Pile, Charles H.
Pinkney, Thomas
Plater, H. R. F.
Pover, W. T.
Pratt, G. H. F.
Price, Arthur, R.N.
Preston, F. G. Panizzi
Preston, H. W.
Putnam, Thos.

Ratliffe, G.
Rawson, Robert, Hon. Mem. Manchester Literary and Philosophical Society
Reincke, Roderich L. Hans
Rendel, Hamilton Owen
Rennie, Keith T.
Renwick, George
Richardson, Thomas, M.P.
Ridley, John H.
Riley, James (Assoc. Mem. Council)
Ritson, Arthur
Robson, George
Rogestvensky, Capt. Z., I.R.N.
Rosenthal, J. H.
Roseti, Lieut.-Com. G. S., Argentine Navy
Rothe, H. P., Commodore, Danish Royal Navy
Rowan, David
Rowley, Charles J., Rear-Admiral
Rugg, C. H.
Ruhm, T. S.
Russell, A. G.

Saborido, Lieut. L., Argentine Navy
Samuelson, Sir Bernhard, Bart., F.R.S.
Sankey, Captain M. H. P. Rial, R.E. (retired)
Sarjeant, W. F.
Saunders, James Ebenezer

Saxe-Coburg and Gotha, H.R.H. the Duke of, K.G., K.T., K.P., G.C.B., G.C.S.I., G.C.M.G., G.C.I.E., Admiral of the Fleet (Vice-President)
Schwanhausser, W.
Scott, Colin W.
Scott, Ernest
Scott, George J.
Seaman, Charles J.
Serena, Arthur
Seymour, Edward Hobart, Rear-Admiral, C.B.
Singer, F. M.
Sloan, W.
Smith, R. Knightly
Spencer, Right Hon. Earl, K.G. (Vice-President)
Spencer, John W.
Starnes, J. S.
Stewart, Andrew
Stewart, J. G.
Stewart, Walter J. L.
Stileman, F.
Suart, A.

Tagg, George John
Tamplin, F. A.
Tamplin, T. Ward
Tapscott, G. L.
Tate, R.
Taylor, George W.
Taylor, W. Isaac
Temperley, Joseph
Terry, Stephen H.
Thomasson, Lucas
Thompson, Stephen
Thomson, Andrew
Thornycroft, J. E.
Thubron, E. Blakelock
Thurston, Robert H., Professor
Tindall, William H. (Vice-President)
Todd, J. Stanley
Trotter, T., Captain

Uribe, Luis, Rear-Admiral, Chilian Navy
Urtubey, Clodomiro, Rear-Admiral, Argentine Navy

Van Raalte, J.
Vassilioff, S.
Vavasseur, Josiah
Vogelsang, Alexander

Wabster, M. P.
Waddilove, Charles L. D., Admiral
Wade, W. S.
Wait, A. M.
Walker, W.
Watkinson, W. H., Professor
Watson, H. Burnett
Watson, Henry James
Watson, W.
Watson, William
Watt, John
Watts, Edmund H.
Wedgwood, J. C.
Westmacott, Percy G. B.
Wharton, William J. L., Rear-Admiral, C.B., F.R.S.
White, J. Bell
White, Robert
Williams, R. W.
Williams, Samuel
Williamson, R. H.
Williamson, W. C.
Wilmot, S. Eardley, Captain, R.N.
Wilson, A. K., Rear-Admiral, V.C., C.B.
Wilson, H. C.
Wingfield, G. J., Com., R.N.
Wise, William Lloyd
Woodall, J. W.
Wort, W. E.

Yamamoto, N.
Younger, Robert L.

Ziffer, J. H.

OBJECTS OF THE INSTITUTION.

The objects of the Institution of Naval Architects—which was established to promote the Improvement of Ships, and of all that specially appertains to them—are comprised under three heads:—

First, the bringing together of those results of experience which so many shipbuilders, marine engineers, naval officers, yachtsmen, and others acquire, independently of each other, in various parts of the country, and which, though almost valueless when unconnected, doubtless tend much to improve our Navies when brought together in the printed Transactions of an Institution.

Secondly, the carrying out, by the collective agency of the Institution, of such experimental and other inquiries as may be deemed essential to the promotion of the science and art of shipbuilding, but are of too great magnitude for private persons to undertake individually.

Thirdly, the examination of new inventions, and the investigation of those professional questions which often arise, and were left undecided before the establishment of this Institution, because no public body to which professional reference could be made then existed.

BYE-LAWS AND REGULATIONS.

CONSTITUTION.

1. The Institution of Naval Architects shall consist of three classes, viz., Members, Associates, and Honorary Members.

2. *Members.*—The class of Members shall consist exclusively of Naval Architects, and Marine Engineers conversant with Naval Architecture.

3. *Associates.*—The Class of Associates shall consist of persons who are qualified either by profession or occupation, or by scientific or other attainments, to discuss with Naval Architects the qualities of a ship, or the construction, manufacture, or arrangement of some part or parts of a ship or her equipment.

4. *Honorary Members.*—The Class of Honorary Members shall consist of persons upon whom the Council may see fit to confer an honorary distinction.

ELECTION AND DUTIES OF OFFICERS.

5. The Officers of the Institution shall consist of a President, Vice-Presidents, Members of Council, Associate Members of Council (not exceeding in number one-third the number of Members of Council), a Treasurer, two Auditors of Accounts, and a Secretary or Secretaries.

6. A General Meeting of the Members and Associates of the Institution shall be held annually before Easter in each year; and at this Annual General Meeting the Members of Council, Associate Members of Council, Treasurer, and Auditors for the ensuing year shall be elected.

7. At the Annual General Meeting Members only shall vote in the Election of Members of Council, and both Associates and Members in the election of Associate Members of Council, the Treasurer, and the Auditors.

8. *President.*—Both Members and Associates of the Institution shall be eligible for election as President. The President shall preside over all meetings of the Institution, and of Officers of the Institution, at which he is present, and shall regulate and keep order in the proceedings.

9. *Vice-Presidents.*—Both Members and Associates of the Institution shall be eligible for election as Vice-Presidents. In the absence of the President, one of the Vice-Presidents shall preside at the General Meetings of the Institution, and shall regulate and keep order in the proceedings.

10. In case of the absence of the President and of all the Vice-Presidents, the Meeting may elect any Member of Council or Associate Member of Council, and in case of their absence any Member present to preside.

11. The Chairman at any Meeting of the Council of the Institution, when the votes of the Meeting, including his own, are equally divided, shall be entitled to give a casting vote.

12. Persons holding the office of Vice-President shall at all times be entitled to sit and vote with the Council.

13. *Past Presidents and Vice-Presidents.*—All Members who have held the posts of President and Vice-President shall, while their connection with the Institution as Members lasts, be entitled to sit and vote with the Members of Council.

14. *Members of Council.*—Members only shall be eligible for election as Members of Council at the Annual General Meeting.

15. *Associate Members of Council.*—Associates only shall be eligible for election as Associate Members of Council at the Annual General Meeting.

16. The Direction and Management of the Institution shall be vested in the Council for the time being, the Associate Members voting with the Members of Council in all cases, except in the decision of questions directly affecting the forms of ships and the construction of their hulls.

17. The Council shall meet as often as the business of the Institution requires, and at every Meeting five Members of the Council shall form a *quorum.*

18. The Council may appoint Committees to report to them upon special subjects.

19. All questions shall be decided in the Council by vote; but at the desire, expressed in writing, of any four Members or Associate Members present, the determination of any subject shall be postponed to the succeeding meeting of the Council.

20. An annual statement of the funds of the Institution, and of the receipts and payments of the past year, shall be made under the direction of the Council, and, after having been verified and signed by the Auditors, shall be laid before the Annual General Meeting.

21. The Council shall draw up an Annual Report on the state of the Institution, which shall be read at the Annual General Meeting.

22. It shall be the duty of the Council to adopt every possible means of advancing the Institution, to provide for properly conducting its business in all cases of emergency, such as the death or resignation of Officers, and to arrange for the publication of the Papers read at the Meetings, or of such documents as may be calculated to advance the objects of the Institution.

23. *Treasurer.*—Only Bankers, or Members of Council, or persons who have been Members of Council and are still Members of the Institution, shall be eligible for election as Treasurer.

24. *Trustees.*—There shall be four Trustees, two of whom shall be the President and Treasurer of the Institution for the time being. The remaining two shall be appointed by, and hold office at the pleasure of the Council. In the names of these trustees, under the direction of the Council of the Institution, all securities shall be taken and investments made, the whole of such property being notwithstanding subject to the disposition of the Council, and the order of the Council in writing, signed by the Chairman of the Meeting and countersigned by the Secretary, shall be obligatory upon and full authority for the Trustees.

25. *Auditors.*—All Members and Associates of the Institution shall be eligible for election as Auditors.

26. The Auditors shall have access at all reasonable times to the Accounts of the pecuniary transactions of the Institution; and they shall examine and sign the annual statement of the Accounts before it is submitted by the Council to the Annual General Meeting.

27. *Secretary.*—The Secretary or Secretaries shall be elected by the Council, and shall be removable at the will of the Council, after due notice given. The salary of the Secretary or Secretaries shall be fixed by the Council.

28. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all Meetings of the Institution and of the Council; to take Minutes of the proceedings of such Meetings; to read the Minutes of the preceding Meeting; to announce donations made to the Institution; to superintend the publication of such Papers as the Council may direct; to have charge of the library, museum, and offices of the Institution; and to direct the collection of subscriptions and the preparation of accounts. He shall also engage, and be responsible for, all persons employed under him, and generally conduct the ordinary business of the Institution.

29. In each year six Ordinary and two Associate Members of Council shall retire, unless before the date of drawing up the Balloting Lists for the election of the Council any Members of the Council shall have died or resigned, in which case only so many members shall retire as shall be necessary in order to make up the number to six Ordinary and two Associate Members of Council, subject always to the provisions of Rule 36. The Members who shall retire in each year shall be those who have served longest on the Council from the date of the last election, and in the event of there being several Members who have served an equal time on the Council, the order of retirement amongst these shall be alphabetical. The retiring Members shall be eligible for re-election.

30. In January of each year the Council shall meet and prepare Lists for the election of the Council for the ensuing year. These Lists shall be as follow, namely :—

1*st.* A List of the names of the President, Vice-Presidents, and Treasurer for the ensuing year to be submitted at the Annual General Meeting, for their election in a body.

2*nd.* A list of candidates to fill any vacancies in the list of Vice-Presidents that it may be intended to fill up from among the professional Members of the Institution.

3*rd.* Lists for the election of the Ordinary Members and Associate Members of Council.

31. No addition shall be made to the list of Vice-Presidents until, by death or resignation, their number shall have been reduced to below twenty-four, after which their numbers shall be raised to and preserved at twenty-four. The vacancies are to be filled up in such a manner that not less than one-half nor more than two-thirds of the total list of Vice-Presidents shall be professional Members of the Institution. Provided

always that the Council shall be at liberty, should special circumstances arise before the numbers shall have been reduced below twenty-four, to provide for the election of one Member and one Associate of the Institution as Vice-Presidents.

32. When any vacancy occurs in the list of Vice-Presidents which it is intended to fill by the election of a professional Member of the Institution, the election shall be by voting papers issued to all Members of the Institution. The candidates to fill the vacancy shall be selected by the Council in the month of January from among the existing or past Members of Council. The number of candidates shall not be less than two for each vacancy, but shall not otherwise be limited. The voting papers shall be issued to the members at the same time as the voting papers for the election of Members of Council, and shall be subject to the same regulations and scrutiny as these latter, as provided for by Rules 37, 38, 39, 40.

33. After having been once elected by voting papers, the Vice-Presidents will be subject to re-election every year in a body at the Annual Meetings.

34. When any vacancy occurs in the list of Vice-Presidents which it is intended to fill by the election of an Associate of the Institution, the nomination to fill the vacancy shall be made by the Council, and the candidate nominated shall be included in the list of Vice-Presidents submitted at the Annual Meetings for election in a body.

35. No addition shall be made to the total number of Ordinary Members of the Council until, by death of resignation, their numbers shall have been reduced below twenty-four, after which their numbers shall be raised to and preserved at twenty-four. And no addition shall be made to the Associate Members of Council until, by death or resignation, their numbers shall have been reduced below eight, after which their numbers shall be raised to and preserved at eight, always exclusive of the President, Vice-Presidents, and Treasurer.

36. At the date of issuing the Syllabus of the Annual General Meetings in each year, the Lists proposed by the Council for the election of Members to fill the vacancies in the Ordinary Council for the ensuing year shall be printed, and sent to all Members to serve as Balloting Lists. These Lists shall contain, first, the names of the retiring Ordinary Members of Council at the time of the preparation of the Balloting List, together with as many new names of Members of the Institution as shall be needed to bring the number up to twice the number of vacancies, and the whole of these names shall be printed in alphabetical order. Secondly, the names of the retiring Associate Members of Council at the time of the preparation of the Balloting List, together with as many new names of Associates of the Institution as shall be needed to bring the number up to twice the number of vacancies, and these names also shall be printed in alphabetical order. From these Lists the vacancies in the Council shall be filled up. Every Member shall be at liberty to vote for as many names on each of the Lists as there are vacancies to be filled, but not for more.

37. A similar Balloting List (in which, however, the names of the Ordinary Members of Council proposed for election shall not be included) shall be printed and sent to all Associates of the Institution, to serve as a Balloting List for Associates, from which the voting for Associate Members of Council shall be taken. Every Associate shall be at liberty to vote for as many names on that List as there are vacancies to be filled, but not for more.

38. The Balloting Lists may be sent by post or otherwise to the Secretary, so as to reach him before the day and hour named for the Annual General Meeting, or they may be personally presented by the Members and Associates at the opening of the Annual General Meeting.

39. At the opening of the Annual General Meeting the order of business shall be :—

(1) To read and consider the Reports of the Council and Treasurer.

(2) To read the List of Officers and Nomination for Council for the ensuing year, proposed by the Council.

(3) The Chairman shall next put to the Meeting the List containing the names of the President, Vice-Presidents, and Treasurer for election for the ensuing year.

(4) The Chairman shall then nominate two Scrutineers (of whom one only shall be a Member of the existing or proposed Council), and shall hand to them the Ballot Boxes containing the Voting Papers for the Ordinary Members of Council and Associate Members of Council ; and

(5) The Scrutineers shall receive all Ballot Papers which may have reached the Secretary, and all others which may be presented by Members or Associates at the Meeting. The Scrutineers shall then retire and verify the Lists, and count the votes ; and shall, not later than the following day, report to the Chairman the names which have obtained the greatest number of votes, subject to the conditions of the Ballot. The Chairman shall then read the List presented by the Scrutineers, and shall declare the gentlemen named in the List to be duly elected, provided always that the List does not contain more names than there are vacancies to be filled. If, in consequence of two or more of the candidates receiving an equal number of votes, the List shall contain more names than there are vacancies, the Council shall, at their next meeting, decide which of these candidate shall be elected.

(6) After the Ballot shall have been taken, and the Scrutineers have retired, the Meeting will proceed to the other business before it.

40. The new Council and Officers shall take office immediately after the close of the Annual General Meeting.

41. In the event of any vacancy occurring in the offices of either President or Treasurer after the date of the Annual Election in any year, the Council shall have power to elect a new President or Treasurer, as the case may be, who shall hold office till the conclusion of the next Annual General (Spring) Meeting of the Institution.

DESIGNATION OF MEMBERS AND ASSOCIATES.

42. Any Member, Associate, Honorary Member, having occasion to designate himself as belonging to the Institution, shall state the class to which he belongs according to the following abbreviated forms, viz., M.I.N.A. ; Assoc. I.N.A. ; Hon. Mem. I.N.A.

ELECTION OF MEMBERS AND ASSOCIATES.

43. *Admission of Members.*—Every Candidate for admission into the Class of Members, or for transfer into that Class from the Class of Associates, shall be more than twenty-five years of age, and shall comply with the following regulations :—

He shall submit to the Council a statement showing that he has been professionally engaged in shipbuilding or marine engineering for at least seven years in some public or private shipbuilding establishment, or marine engine works, and setting forth the grounds upon which he bases his claims to be considered a professional Naval Architect, or Marine Engineer conversant with Naval Architecture, and to be admitted as such to the Membership of the Institution. This shall be

signed by at least three Members, whose signatures shall certify their personal knowledge of the Candidate, and approval of his statement; or, in the case of persons not British born, the signatures of three Members shall be required, in confirmation of their personal knowledge of the Candidate's scientific reputation.

44. These preliminary conditions being satisfied, the Council shall then consider whether the practical experience and professional attainments of the Candidate are such as entitle him to be brought forward by the Council as a Naval Architect, or Marine Engineer conversant with Naval Architecture. If four-fifths at least of the received votes of the professional Members of the Council are in favour of his application, his proposal for admission shall be submitted to the Members of the Institution (who shall have access to the applicant's statement), at an Ordinary Meeting of the Institution, for them to vote upon, the voting to be by ballot, should a ballot be demanded.

45. *Admission of Associates.*—Candidates for Associateship shall submit to the Council a proposal for their admission, setting forth therein a statement of their claims to be admitted as Associates. Their proposal, if approved by the Council, shall be submitted by them at an Ordinary Meeting of the Institution, for the Members and Associates jointly to vote upon, the voting to be by ballot, should a ballot be demanded.

46. The proportion of votes for deciding the election of Members and Associates shall be at least four-fifths of the numbers recorded.

SUBSCRIPTIONS.

47. Each Member and Associate shall pay an Entrance Fee of two guineas, and an Annual Subscription of two guineas in advance; the first Subscription being payable on his election, and all future ones on the 1st day of January of each year. Any Member or Associate withdrawing from the Institution after that date is still liable for the amount of Subscription due on that day.

48. Any Member or Associate may compound for his Annual Subscription, for life, by a single payment of not less than thirty guineas.

49. No person's name shall be entered on the Roll as Member or Associate of the Institution nor possess the privileges of Membership (except it be on the honorary list) until he shall have paid his first subscription or the life composition, and if the payment be delayed for more than twelve months from the date of his election, the same shall be void unless the Council otherwise direct.

50. The Secretary shall at the close of every year notify to all Members and Associates whose subscription for that year shall not have been paid, that it will be his duty to report accordingly to the Council, and he shall at the same time furnish the person whose subscription is in arrear with copies of this and the two following Rules.

51. The Secretary shall before Easter in every year lay before the Council a list of all Members and Associates whose subscriptions for the two previous years shall be still unpaid, and unless the Council shall otherwise direct, the names of those in arrear shall be expunged from the Roll of Members and Associates, and shall not be replaced without re-election in due form. Provided always that the Council shall at any time within two years therefrom have power to dispense with such re-election, and to restore the name to the Roll upon payment of all subscriptions then due, and upon cause being shown to the satisfaction of the Council why such subscriptions were not previously paid.

52. Nothing herein contained shall prejudice the right of the Institution to the legal recovering of all arrears of subscriptions up to the date of striking the name off the Roll.

53. In case the Council shall be of opinion that any Member, who has been long distinguished in his professional career, from ill-health, advanced age, or other sufficient causes, should not be called upon to continue his annual subscription, they may remit it. Also they may remit any arrears which are due from an individual, or may accept a collection of books, or drawings, or models, or other such contribution as, in their opinion, under the circumstances of the case, may entitle the person to be enrolled as a Life Subscriber, or to enable him to resume his former rank in the Institution which may have been in abeyance from any particular causes. These cases must be considered and reported upon by a Sub-Committee named for the purpose.

54. In case the expulsion of any individual shall be judged expedient by ten or more Members, and they think fit to draw up and sign a proposal requiring such expulsion, the same being delivered to the Secretary shall be by him laid before the Council. If the Council, after due inquiry, do not find reason to concur in the proposal, no entry thereof shall be made in any Minutes, nor shall any public discussion thereon be permitted; but if the Council do find good reason for the proposed expulsion they shall direct the Secretary to address a letter to the person proposed to be expelled, advising him to withdraw from the Institution. If that advice be followed, no entry on the Minutes nor any public discussion on the subject shall be permitted; but if that advice be not followed, nor a satisfactory explanation given, the Council shall call a Special General Meeting of Members and Associates, for the purpose of deciding on the question of expulsion; and if two-thirds of the persons present at such Special General Meeting, providing the number so present be not less than thirty, vote that such individual be expelled, the Chairman of that Meeting shall declare such expulsion accordingly, and the Secretary shall communicate the same to the individual.

MEETINGS.

55. Meetings for the Reading of Papers shall be held as frequently, and at such times, as the Council may determine.

TRANSACTIONS.

56. The *Transactions* of the Institution, including the Papers read at the Ordinary Meetings, and Reports of the Discussions by which they are followed, shall be edited by the Secretary, and printed under the direction of the Council.

57. A copy of each Volume of *Transactions* shall be sent free to every Member and Associate.

58. The Secretary, under the direction of the Council, may dispose of the surplus stock of *Transactions* which have been published more than three years, at a price of not less than One Guinea a volume, provided a sufficient number remain on hand to supply the probable demand of New Members and Associates to complete their sets by the purchase of the back Volumes.

CHANGE OF ADDRESS.

59. Members and Associates are particularly requested to communicate to the Secretary any change of address.

PROCEEDINGS IN PARIS.

SUMMER MEETINGS OF THE THIRTY-SIXTH SESSION

OF THE

INSTITUTION OF NAVAL ARCHITECTS.

JUNE 11, 12, 13, 14, AND 15, 1895.

INTRODUCTORY PROCEEDINGS.

The Summer Meetings of the Thirty-sixth Session of the Institution of Naval Architects were held in the large hall of the Sorbonne in the Rue des Ecoles, Paris, on June 11, 12, and 13.

The proceedings commenced with a welcome to the Institution by Vice-Admiral Charles Duperré, President of the Reception Committee, and by Monsieur Baudin, on behalf of the Municipality of Paris.

Afterwards the Right Hon. Lord Brassey, K.C.B., President of the Institution, took the chair.

Vice-Admiral Charles Duperré (President of the Reception Committee) in opening the proceedings, delivered an address in French, of which the following is a translation:—Gentlemen, the Reception Committee, including Representatives of the Government of the Republic, the National Navy, the French University, the Chamber of Commerce, and of scientific institutions, as also of industrial companies and establishments, extends to you all a hearty welcome. The authorities of your Institution have had the happy idea of choosing Paris as the place of meeting for your session of 1895, and you now leave British soil for the first time. We thank you for the choice thus made, and hope that the mingling of English and French shipping specialists which is now about to take place will have most valuable results. Your initiative in coming to see us and making yourselves acquainted with us, and letting us see and become acquainted with you, is one that is calculated to at once cement the sympathies of individuals and the friendships of nations. With people animated by the same humanitarian spirit, the same ardour in the pursuit of what is good and noble, to know and appreciate each other is to like one another. We beg to assure you that we are delighted to have you amongst us, and we ask you to continue your labours under the ægis of this Sorbonne, which for six centuries has been an arena for oratorical tournaments and intellectual strife. This Institution will now record as a memorable fact in its history that it has been the meeting-place of the first congress ever held abroad by the great Institution of Naval Architects. (Loud and continued applause.)

Monsieur Baudin (Vice-President of the Municipal Council of Paris) next spoke, also in French, to the following effect:—My Lord and gentlemen, as representing the city of Paris, I venture to add a few words to the cordial expression of welcome that has just been addressed to you by Vice Admiral Duperré. The city of Paris, gentlemen, claims to welcome you on its own special behalf. We feel extremely flattered in that you have chosen the Parisian city as your rendezvous on this occasion; we are very happy to number you amongst our guests, belonging as you do to so celebrated and powerful an Institution; and we are especially proud to have as our guests, Lord Brassey, Sir Nathaniel

Barnaby, and Sir William White, whose labours have shed such glory upon your Institution as a whole, and whose presence here is particularly gratifying to us. We hope, gentlemen, that your sojourn in this city will remain graven in your memory, not only by reason of the utility of the labours connected with this Congress, but also as a recognition of Parisian hospitality, which the city desires should be of the most cordial character, and an evidence of the friendly feelings it entertains towards the Institution of Naval Architects. We hope that something of its beauty, its heart, and *esprit* may enter into you and exercise a charm upon you. Gentlemen, the Municipal Council of Paris invites you to a reception on Friday next, when we shall be truly delighted to have you with us to fête you, and to celebrate that union which Vice-Admiral Duperré has described in such elevated terms as the "union of two nations." We feel deeply sensible of the honour now conferred upon France, and in welcoming the Institution of Naval Architects we express a fervent hope that it may have as full a meed of prosperity in the present and the future as in the past.

The President (the Right Hon. Lord Brassey, K.C.B.): It now becomes my duty to reply on behalf of the Institution of Naval Architects to the speeches which have been delivered. Our thanks are due to all our kind hosts, especially to the President of the French Republic, who, when Minister of Marine, was the first to take up and encourage the idea of the proposed visit of our Institution to Paris; to Vice-Admiral Besnard, the present Minister of Marine, who is the Honorary President of the Reception Committee; to Vice-Admiral Charles Duperré, President, and the members of the Reception Committee; to M. Bertin, Chairman, and those associated with him on the Executive Committee; and to M. Octave Gréard, Rector of the University of Paris, by whose kind permission we are assembled to-day in the amphitheatre of the Sorbonne. Our Institution has indeed been highly honoured. Your splendid Navy, your Naval Architects, Engineers, Shipbuilders, and Shipowners, your men of science, and your yachtsmen, are represented on the Reception Committee. We fully appreciate the immense trouble you have taken to secure complete success for the first meeting our Institution has held in a foreign country. It was fitting that that meeting should be held in France. Our French colleagues, MM. de Bussy, Berrier Fontaine, Bertin, Normand, and Daymard, have been among the most regular attendants at our meetings and the ablest speakers at our discussions.

Having discharged, though most imperfectly, the agreeable duty of expressing our thanks, I proceed to offer a few general observations. And first, I desire to say that we are here not only to exchange international courtesies. That is indeed a most important duty, for which every suitable opportunity should be eagerly seized. But we are here also to gain instruction. You have taught us much, and will always have many things to teach us. I am reminded, in an able memorandum prepared by Mr. Martell, principal surveyor of Lloyd's, that it was under the famous administration of Colbert that mathematical science was first successfully applied to naval construction. It was long before the same judicious blending of theory and practice was adopted in our own country. For a considerable period French ships were markedly superior in model to those of British construction. Descending to later times, I am reminded by our colleague, Sir Nathaniel Barnaby, that your *Napoléon* was the first steam line-of-battle ship seen in any navy. The first ironclad ship ever built was the *Tonnante*, launched at Brest in March, 1855. The first seagoing ironclad was the *Gloire*, launched in 1858. These three ships, each being the pioneer of a new type, owed their origin to the genius of M. Dupuy de Lome.

If from design we turn to the materials used in construction, the first step in the substitution of steel for iron in armour plates was made in France by M. Henri Schneider. He has produced plates

of the unrivalled thickness of 22 in. It is also to France, to your constructors at L'Orient and Brest, that the credit belongs of having been the first to use the modern soft steel plating for building the hulls of ships. As in the building of the hulls, so in the manufacture of machinery and boilers we are greatly indebted to French inventors. For our latest cruisers—ships of dimensions never before approached, which we are naturally anxious to make in all respects as perfect as possible—we have come to France for that primary source of vitality in a steamship, I mean the boilers. They will be of a new type, the invention of one of our kind hosts in Paris, M. Delaunay Belleville.

If we turn from the construction of ships and machinery to the literature of the subject, the contributions of French authors have ever been held in the highest esteem in England. Bouguer, whose "Traité des Navires" was published in 1746, was the first to make a theoretical investigation of the stability of floating bodies. The true theory of the rolling of ships in still water was first established by Bernouilli, almost a contemporary of Bouguer. The subject of stability was again taken up by M. Dupuis, who published in 1814 a series of original and brilliant geometrical theorems, still used, as I learn from Mr. Martell, with advantage by English writers. Coming to more recent times, we owe to M. Reech our knowledge of the laws of wave motion and resistance, as described in his "Cours de Mécanique," published in 1852. The most recent investigations on the same subject, and they are of great value, are those of MM. Bertin, Antoine, Duhil de Benaye, and Risbec; M. Daymard's paper on "Stability," read in 1884, is one of the most important papers which have been published in the thirty-five volumes of our Transactions.

It is almost time that I should conclude a speech which, being delivered in a foreign accent, must be painful to French ears; but before I sit down I should like to say a few words on a great maritime enterprise with which, for a time, I was connected as a Director, and in which France and England have worked together for the beneficent purposes of commerce and civilisation. I allude to the Suez Canal. The construction of the Canal was wholly your work. Against every opposition—even, I regret to say, that of England—the work was achieved, under the inspiration derived from a great Frenchman, whom you have recently lost. In making the Suez Canal a success, England can certainly claim no more merit than belongs to the labourer of the eleventh hour. Yet we have played, though a humble, but a useful part. We have helped to make the undertaking pay. We have been by far the largest contributors to the revenue of the company. I regard the co-operation of France and England in the Suez Canal as a happy augury for the ultimate friendly solution of those political problems, created by the Suez Canal itself, with which we here have happily nothing to do. The results achieved by the combined enterprise of the two nations indicate and illustrate the lines of peaceful progress by which, in friendly co-operation, the two countries have it in their power to do so much for the advantage of mankind. Believe me, it is the highest ambition of the members of the Institution of Naval Architects to find themselves associated in the enterprises of peace with their French colleagues. We come here to-day warm friends and admirers of that gifted French nation, to which, in every branch of human thought and effort, in political ideas, in culture, in literature, in art, in industry, invention, and practice, the world owes so much. It gives me peculiar pleasure to be here to-day in the position which I have the honour to fill. I spent a great part of my childhood in this country. My father came here by your invitation as the pioneer contractor, to organise works and workmen in the construction of those great railways which, in an incredibly short time, you learned to construct for yourselves. I remember with gratitude the fair and liberal spirit with which my father, a stranger in your midst, was treated by his French employers. Once more, in the name of the Institution of Naval Architects, I return their cordial acknowledgments for your generous and friendly welcome.

THE AMPLITUDE OF ROLLING ON A NON-SYNCHRONOUS WAVE.

(Second Notice.)

By Monsieur Emile Bertin, Directeur des Constructions Navales et Directeur de l'Ecole d'Application du Génie Maritime; Member.

[Read at the Summer Meeting of the Thirty-sixth Session of the Institution of Naval Architects, June 11, 1895; the Right Hon. Lord Brassey, K.C.B., President, in the Chair.]

Last year I resumed the study of the amplitude of rolling at the very moment when the same subject was brought to the notice of practical men by Sir William White, owing to the rolling of the *Resolution*. This coincidence may be the means of obtaining a more practical result in the researches on a question the treatment of which was left unfinished for more than twenty years. In this somewhat obscure subject calculation and observation must go hand in hand. Important tests have been made on the first-class battleships of the British Navy, and the mathematical treatment of the matter must not lag behind.

I gave in 1894 a table of the inclinations or successive semi-amplitudes for one particular series of rolls, and I shall now consider a sufficient number of cases to embrace the question generally, without even excluding the case of synchronism with the swell and maximum rolling. I shall assume that the waves have a constant inclination of 10°, or, rather, I shall continue to assume that—

$$K^2 \Theta = 10°, *$$

the constant K^2 being approximately equal to unity.

I shall continue to represent the $\delta \psi$ by the broken line A A A, in Fig. 3 (Plate XXXIX., Vol. XXXV.), although any curve whatever, even if non-symmetrical, for the crests and hollows of the waves, and as exact as can be drawn, may be substituted for A A A without causing any complication in the resultant curves or in the calculations.

The graphic method used in 1894 makes it easy to take note of the requirements of the general method adopted and of the degree of error that it permits in the hypothesis.

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* The symbols have the same meaning as in the paper above referred to. Transactions Inst. of Naval Architects, Vol. XXXV. p. 187.

Variables upon which the Apogee Roll Depends.*

Only two data are required besides the inclination Θ of the waves in order to construct Fig. 3 (Plate XXXIX., Vol. XXXV.); firstly, the co-efficient N of the decrease of rolling in still water; secondly, the number m of successive rolls during which $\delta\psi$ would be increasing or decreasing in a non-resisting medium.

The co-efficient N is a characteristic datum of the vessel, it is determined after a trial of rolling in still water; the case of the *Repulse* compared with the *Resolution* has proved once more that it can be varied within wide limits.

We shall have to refer later on to the meaning of N, but I will designate by "co-efficient of clisity" the square root of the reciprocal of N or—

$$E = \sqrt{\frac{1}{N}}.$$

The term m depends upon the two periods of the roll and of the swell, and it may be expressed algebraically—

$$(1) \qquad m = \frac{1}{2}\frac{T_n}{T_n - T};$$

whence

$$(2) \qquad \frac{1}{m} = 2\left(1 - \frac{T}{T_n}\right).$$

It must be noted that the total number of rolls, in a complete cycle of increasing and then decreasing amplitude, is equal, not to $4m$, but only to $4m - 2$, for the roll of apogee amplitude is common to the increasing portion and also to the decreasing portion, and the vanishing rolls are common to two successive series. This term $4m - 2$ is expressed very simply—

$$(3) \qquad 4m - 2 = 2\frac{T}{T_n - T}.$$

The greatest inclination Ψ, which is that in the middle of the series, is expressed thus :—

$$(4) \qquad \Psi = (m - 1)\,\Theta.$$

The factor $(m - 1)$, which may be called the *co-efficient of agreement*, and which expresses the influence of the relation of the periods upon the amplitudes ψ and ϕ in Fig. 3 (Plate XXXIX., Vol. XXXV.), is expressed thus :—

$$(5) \qquad m - 1 = \frac{2\,T - T_n}{2\,(T_n - T)};$$

or

$$(5a) \qquad m - 1 = \frac{2\,T_n - T}{2\,(T - T_n)}$$

According as T_n or T is the greater, so we use one or other of these equations.

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* Apogee roll is the greatest roll in a series on a non-synchronous swell. Maximum roll is the greatest on a synchronous swell.

Method Used for Determining the Amplitude of the Apogee Rolling.

The necessity for treating a very great number of particular cases in order to determine with some accuracy the laws of relation between Φ_a, and N and $(m - 1)$ has induced me to seek some simplification in the method of calculation.

After having first simplified the rough trials used in drawing Fig. 3, it has been found that a saving of time can be obtained by abandoning the diagram and by calculating directly the successive ordinates of the curve ϕ in the following manner:*—

In Fig. 3 (Plate XXXIX., Vol. XXXV.), let us call χ the ordinates of the curve C C C, which are equal to the difference between the ordinates ψ of the curve B B B, composed of two known parabolic curves, and the ordinates ϕ of the unknown curve E E E. Upon any ordinate of the order n we have by the known law for the effect of the resistance of water—

$$N\,\varphi_n^2 = \delta_n \chi = \chi_n - \chi_{n-1}\,; \tag{6}$$

We have on the other hand,

$$\chi_n = \psi_n - \phi_n$$

$$\chi_{n-1} = \psi_{n-1} - \varphi_{n-1}$$

$$\therefore\ \chi_n - \chi_{n-1} = (\psi_n + \phi_{n-1} - \psi_{n-1}) - \phi_n. \tag{7}$$

In this equation the expression within the brackets is always of known value, when we pass from one to the following ordinate. From equations (6) and (7) we have

$$N\,\phi_n^2 + \phi_n - (\psi_n + \phi_{n-1} - \psi_{n-1}) = 0\,; \tag{8}$$

this is a quadratic equation, whence ϕ_1 can be calculated by making $\phi_0 = 0$, and afterwards ϕ_2, by giving to ϕ_1 the value obtained; the same method applies to ϕ_3, and so on, as all the values of ψ are known.

It must be noted that here, as well as in the graphic method used in 1894, the preceding calculation is independent of all hypotheses as to the values of $\delta\,\psi$ and of ψ; therefore other values of $\delta\,\psi$ might be taken than

$$\delta\,\psi = (29 - 1)\,K^2\,\Theta. \tag{9}$$

Equation (8) is always solved in the same way when the successive numerical values of ψ are known.

In the same way the formula (6) for the reduction of amplitude due to passive resistances may be replaced by any other quadratic expression of ϕ_n, such as—

$$N_1\,\phi_n + N_2\,\phi_n^2\,;$$

The form of equation (8) would be slightly altered, but the difficulty in calculation would not be increased.

* These successive simplifications were introduced by the students in the Ecole du Génie Maritime, and the final formula is due to M. Faure, one of the students.

I have limited myself to the very simple hypothesis used in my paper of 1894, including that of $K = 1$, because I was not aware of any others of which the superiority was well established. I must, however, make a reservation upon two points :—

(1) In the law for $\delta\psi$ and ψ it is understood that the complete series of increasing, and then decreasing rolls consists of a sufficiently large number of rolls—say, for example, ten or twelve.

(2) The form of the expression (5) shows that the least error in the value of T alters very greatly the value of $m - 1$ when 2 T and T_n differ a little in magnitude, and when therefore m is approximately equal to unity.

For these two reasons it is useless to seek experimental corroboration of the results which we are about to calculate when m is of less value than 3; doubtless no greater accuracy can be obtained when m is of less value than 4. The calculations made when taking $m-1 = 2$ are only made with a view of extending the curves, so as to make them more regular in the part which is of real use.

Results of the Calculations.

The calculations were made for sixty-three series of rolls corresponding to seven values of N between the limits 0·004 and 0·048, within which all the observed co-efficients of decrease fall, and to nine values of m between the limits 2 and 10, beyond which the conditions do not differ materially from those of synchronism.

All the results are tabulated in the Appendix, and were used for drawing the two series of curves of amplitude on the summit of the wave, Figs. 1 and 2, Plates I. and II.

In Fig. 1 are given the curves of apogee rolls corresponding, in each case, to a value of $m - 1$; besides this a series of curves is drawn representing similarly, as a function of N, the numbers of complete rolls in each series, including the initial zero roll and the final roll immediately preceding that which would be the negative or the zero roll, if the law of decrease were to still hold good.

The first series of curves has for initial ordinates the values of Ψ given by the equation (4), and the entire series is an asymptote to the axis of x, or, rather, of N.

The second series of curves has for initial ordinates the values of $4\,m-2$, given by equation (3).

In Fig. 2 is shown the series of curves of apogee inclinations, in which each corresponds to a particular value of N.

Where N = 0, a straight line is obtained, represented by equation (4); for all the other values of N curves are obtained which are asymptotes to parallels with the axis of $(m-1)$ lines, which are shown dotted. The distance of the parallel lines from the axis of $(m-1)$ being given by the formula of the maximum roll—

$$\Phi = \sqrt{\frac{\Theta}{N}} = E\sqrt{\Theta} \tag{10}$$

The total number of the curves of Φ_a in the two figures represents the surface of Φ_a in terms of $m - 1$ and of N.

It will be observed that this surface passes through the axis of N, cuts the plane of $(m-1)$ Φ_a in a straight line, is an asymptote to the plane of $(m-1)$ N on the side of the N's of infinite value, and lastly is an asymptote to a cylindrical surface generated by lines parallel to the axis of $(m - 1)$ on the side of $(m - 1)$ approaching infinity.

A very small number of points is required to determine with precision the development of a surface under such exact conditions.

The following Table sums up the results, and shows how Φ_a varies as a function of $m - 1$ and of N, the top horizontal line gives the values of Ψ.

TABLE I.

N.	$E = \sqrt{\frac{1}{N}}$	Φ Maximum Roll. $m - 1 = \infty$	Φa Apogee Rolls.			
			$m - 1 = 9$	$m - 1 = 7$	$m - 1 = 5$	$m - 1 = 3$
0·000	∞	∞	90°	70°	50°	30°
0·004	15·81	50·0	39·28	36·07	31·20	23·23
0·012	9·13	28·87	25·27	24·01	21·90	17·85
0·020	7·07	22·36	20·25	19·39	17·92	15·06
0·028	5·98	18·90	17·26	16·65	15·57	13·33
0·036	5·27	16·66	15·40	14·92	14·00	12·15
0·044	4·77	15·07	14·00	13·61	12·89	11·72

The number of rolls composing a complete series is shown in the following Table, in which the top horizontal line represents the values of $(4\ m - 2)$.

TABLE II.

N.	Number of Rolls in the Series.				
	$m-1=\infty$.	$m-1=9$.	$m-1=7$.	$m-1=5$.	$m-1=3$.
0·000	∞	38 0	30 0	22·0	14·0
0·004	∞	25·5	21·5	16·6	11·4
0·012	∞	24·2	19·8	15·4	10 6
0·020	∞	23·6	19·2	14·9	10·3
0·028	∞	23·1	18·9	14·6	11·1
0·036	∞	22·8	18·6	14·3	9·9
0·044	∞	22·7	18·5	14·2	9·8

Lastly, in order to show how the rolls follow each other in a series, as they precede and succeed the apogee roll, the number of the decreasing rolls being somewhat greater than that of the increasing rolls, I have drawn in Figs. 3 and 3A, Plates III. and IV., the diagram of Fig. 3 (Plate XXXIX., Vol. XXXV.) for the two values of $m - 1$ equal to 3 and to 9, and for six out of the seven values of N from the tables in the Appendix; the curves B and E only have been shown.

Discussion of the Results.

Amongst these numerical results the only ones of importance are those relating to the inclination of the summit Φ_a. It is especially necessary to note the distinct influence of the co-efficient of decrease N, or of the co-efficient of clisity E, on the one hand, and of the co-efficient of agreement $m - 1$, on the other hand, observing how preponderance is sometimes on the side of the resistance and sometimes on the side of agreement.

Let us consider in Table I. of the values of Φ_a the two extreme values of N, namely 0·004 and 0·044, and let us take for each of them the two extreme values $(m - 1) = 9$, and $(m - 1) = 3$; then, in the four cases, let us calculate the relation of the inclination of the apogee roll Φ_a to the amplitude Ψ in a non-resisting medium and we obtain the following Table:—

TABLE III.

N = 0·004. E = 15·8.		N = 0·044. E = 4·77.	
$m-1=3$.	$m-1=9$.	$m-1=3$.	$m-1=9$.
$\Psi = 30°$	$\Psi = 90°$	$\Psi = 30°$	$\Psi = 90°$
$\Phi_a = 23·23$	$\Phi_a = 39·28$	$\Phi_a = 11·72$	$\Phi_a = 14$
$\frac{\Phi_a}{\Psi} = 0·77$	$\frac{\Phi_a}{\Psi} = 0·44$	$\frac{\Phi_a}{\Psi} = 0·39$	$\frac{\Phi_a}{\Psi} = 0·16$
$\frac{0·77}{0·44} = 1·75$		$\frac{0·39}{0·16} = 2·44$	

This Table, in which E and $(m-1)$ vary almost in the same proportion, namely, that of 3 to 1, shows that, for cases of great resistance, a given diminution of the co-efficient of agreement $(m-1)$ produces a reduction in amplitude relatively larger than in cases where the resistance is small.

If we had gone beyond the limits of the Table for Φ_a, and taken $(m-1)$ as equal to 1, the effect would have been still more pronounced, for the ratios 1·75 and 2·44 would have become 2·16 and 4·37.

If, in the preceding Table, we reverse the columns in the following manner :—

TABLE IV.

$m-1=3$.		$m-1=9$.	
E = 15·8.	E = 4·77.	E = 15·8.	E = 4·77.
$\Psi = 30°$	$\Psi = 30°$	$\Psi = 90°$	$\Psi = 90°$
$\Phi_a = 23·23$	$\Phi_a = 11·72$	$\Phi_a = 39·28$	$\Phi_a = 14$
$\frac{\Phi_a}{\Psi} = 0·77$	$\frac{\Phi_a}{\Psi} = 0·39$	$\frac{\Phi_a}{\Psi} = 0·44$	$\frac{\Phi_a}{\Psi} = 0·16$
$\frac{0·77}{0·39} = 1·97.$		$\frac{0·44}{0·16} = 2·75.$	

we see that for high values of $(m-1)$, that is to say, when synchronism and the conditions of maximum roll are approached,

(10) $$\Phi = E\sqrt{\Theta}$$

a given diminution of the co-efficient of clisity E produces a diminution of amplitude relatively greater than for low values of $(m - 1)$.

In order to observe the point of reversal of the relative effect of the two co-efficients $(m - 1)$ and E, dealt with in the equations (4) and (10) for the extreme cases, it is only necessary to examine the following table. The two values of E there considered are 10 and 5, the one double the other, and corresponding to two very usual values of N—namely, 0·01 and 0·04. The values of $m - 1$ diminish, and follow a geometrical progression with the common ratio 2, descending to $m - 1 = 1$, a value below those dealt with hitherto; the values of Φ_a placed opposite each other in the same horizontal line correspond to the same value of the product $(m - 1) \times E$:—

TABLE V.

$m - 1$	Φ_a where E = 10, and the $(m - 1)$ shown on left.	Φ_a where E = 5, and the $(m - 1)$ shown on right.	$m - 1$.
	Degs.	Degs.	
∞	31·61	15·81	∞
8	26·26	,,	16
4	21·41	14·41	8
2	14·93	12·72	4
1	8·97	10·05	2
0·5	,,	7·20	1

It follows from this Table that the value of E preponderates between the limits $(m - 1) = \infty$ and values of $(m - 1)$ approaching 2: that is to say, for all rolls having a semi-amplitude of more than 12° or 15°, which are the most important for consideration, and for all cases to which our method of calculation is applicable.

It will be observed that for $(m - 1) = 2$ the value of Φ_a is approximately 15° in the first column and 10° in the second column; the amplitude is thus reduced by one-third for a reduction of one-half of the value of E.

An Empirical Expression for the Amplitude at the Apogee Roll.

The two series of curves in Figs. 1 and 2 certainly afford the readiest means of obtaining the value of the inclination Φ_a, or semi-amplitude of the apogee roll, which ought to correspond with the values given of $(m - 1)$ and of N. It may be desired,

however, to deduce from these curves an empirical expression which may be called the theoretical value of Φ_a until theory has advanced still further.

For this purpose, if the various curves in Fig. 1 be taken, they can be represented by the formula—

$$\Phi_a = Q\left(\frac{10}{N}\right)\gamma, \tag{11}$$

the value of $K^2\,\Theta$ being equal to 10, the two constants Q and γ vary from one curve to another so as to represent the influence of the characteristic datum $(m-1)$.

The values of γ and of Q are as follow :—

TABLE VI.

$m-1$	γ Constant for each Value of $m-1$.	Q (Slightly Variable.)		
		N = 0·012	N = 0·036	Mean.
3	0·345	1·746	1·741	1·743
4	0·378	1·581	1·577	1·579
5	0·403	1·447	1·448	1·448
6	0·421	1·356	1·355	1·356
7	0·435	1·287	1·286	1·286
8	0·448	1·215	1·215	1·215
9	0·455	1·184	1·185	1·185

As it was to be expected γ becomes less as $m-1$ diminishes; it approaches the value $\frac{1}{2}$ in proportion as $m-1$ is greater and as synchronism is approached.

The variations of Q in formula (11) when γ remains constant are insignificant.

If it be desired to obtain a single formula containing the two characteristics $(m-1)$ and N, the following equation might be tried :*—

$$\Phi_a = \left\{(m-1)\,\Theta\right\}\frac{1}{1+\propto N}\,(m-1)\left\{\sqrt{\frac{\Theta}{N}}\right\}\frac{1+\frac{1}{\beta}}{N\,(m-1)} \tag{12}$$

This appears to satisfy in the simplest possible manner the general conditions imposed on the surface of Φ_a, in accordance with what was said on page 5 in connection with the two equations (4) and (10).

* This equation (12) might replace the two hypothetical formulæ (108) and (112) as given at pages 339 and 491 of the third volume of "Naval Science."

It remains to be seen if the two points at which the real surface and the surface (12) would be made to coincide by using the arbitrary co-efficients α and β could be so chosen as to furnish a general coincidence between the two surfaces. Formula (12) does not appear very suitable for practical application, I therefore do not undertake this calculation.

Experimental Proofs.

Experimental proofs have much more to do with the part played by N than with that of $(m - 1)$, for the value of the latter co-efficient can rarely be obtained at sea with accuracy.

With regard to N these proofs relate to two different points: in the first place, to the increase of the resistance that can be obtained in water, the moment of resistance being represented in the expression for N according to the formula

$$N = \frac{1}{43} \cdot \frac{M_1}{\Sigma m r^2}; \tag{13}$$

in the second place, to the influence of N as it is obtained by equation (11).

It is, therefore, necessary to take note accurately of the results of tests in still water and of observations taken at sea. The inclinations taken at sea always relate to the absolute roll as obtained by sighting apparatus; the values of Φ_a in equation (11) apply to relative rolling, since Φ_a vanishes when $2\,T = T_n$ or when $2\,T_n = T$; but, notwithstanding this, the inclinations are comparable between themselves because the great angles of rolling are reached on the summits and in the hollows of the waves (Fig. 1, Plate XXXIX., Vol. XXXVI.; and Figs. 3 and 3A, Plates III. and IV. of the present paper).* The first attempt to increase M_1, and therefore N, in a great degree took place about twenty years ago. It was tried upon the gunboat *Crocodile*, whose moment of resistance, M_1, before the addition of bilge keels, had not been measured.

This moment had been estimated as a function of the length l and beam m of the vessel by means of the formula—

$$M_1 = 0{\cdot}002\, l\, m^4 = 246\, T^x\ M. \tag{14}$$

The bilge keels which we added presented a surface S and a distance d from the centre of gravity; their resistance could, therefore, be estimated as follows: —

$$\Delta\, M_1 = 0{\cdot}4\, S\, d^3 = 470\, T^x\ M. \tag{15}$$

According to tests made on a large scale, the moment of resistance expected after the addition of the bilge keels was thus—

$$M_1 + \Delta\, M_1 = 716\, T^x\ M.$$

* In these figures the summits of the curves E E are not far from the summits of A A, even for $(m - 1) = 3$, owing to the passive resistance.

A trial in still water gave a slightly less value of 653 T^x, M being 2·6 times the estimated resistance without keels. This result was considered as a very sufficient proof of the accuracy of the formulæ (14) and (15).

The co-efficient N was reduced in the ratio 2·6, and the co-efficient of clisity E in the ratio 1·6, when compared to a gunboat unprovided with bilge keels.

Some observations of rolling were made with the duplex oscillograph during the trials of the vessel, and of these I have published the results.

It seems to me that the clisity had been diminished in a somewhat greater ratio than 1·6. On a swell of 3·1 seconds for a half period, the amplitude of roll did not exceed 7° on one side, although, according to my estimate, it ought to have been 10° to 15° on a vessel without a keel.*

The co-efficient N of the *Crocodile* was 0·033, and the half period of rolling 3·6 seconds. The half period of the waves was 3·1 seconds; therefore giving $m - 1$ a value = 2·6. In these conditions the value of Φ_a would be 12°, according to the curves of Fig. 1.

The addition of bilge keels to the *Crocodile* appears, therefore, to have had the desired effect.

In the course of its active service this gunboat has never sailed in the company of a vessel of similar rolling period, unprovided with bilge keels. In these circumstances, therefore, the quality of seaworthiness due to the addition of keels is quite unappreciated. I do not believe that any report has been given as to her rolling at sea.

Other similar gunboats also provided with bilge keels have been, I believe, reported on as good sea boats, but without any exact figures being given. The general results were therefore rather discouraging, as it appeared almost impossible to fit large vessels with keels of such ample proportions. The field therefore remained open for a test of the same kind followed by decisive trials at sea. This is the test which Sir William White has been able to carry out upon a much larger scale, and which he has described in his "Notes on Further Experience with First-class Battleships." This work has the honour of having definitely solved the problem which had been allowed to rest since 1875.

I will now express the chief results of the trials of the rolling of the *Revenge* in still water in such a way as to render them comparable with data of the same kind which I have had by me for a long time; this will render more striking the novelty and importance of these results.

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* Observations de roulis et de tangage faites avec l'oscillographe double. See page 26 of the note communicated to the Académie des Sciences, Savants Etrangers. Volume XXVI.

I have taken by preference the measurements during the decrease of rolling with and without keels, made when the vessel was at light draught, because the draught of water and the metacentric height remained practically constant throughout the trials.

The curves for decrease of rolling are drawn by taking as abscissæ the squares of the inclinations, and are given in Fig. 4, Plate V.; they give the following results, in which I have introduced the angles of maximum rolling for the inclinations of the waves employed in my former papers, and I reproduce for comparison the figures relating to the *Suffren*.

TABLE VII.

Vessels.	A.	N.	E.	Maximum roll Φ.	
				θ = 8°·75.	θ = 17°·45.
Revenge without keels	0°·074	0°·0036	16·66	49°·3	69°·6
,, with keels	0°·203	0°·0276	6·02	17°·8	25°·1
Suffren	Very slight.	0°·0083	10·98	32°·0	47°·0

The clisity of the *Revenge* has, therefore, been reduced in the ratio 2·76 to 1, while on the *Crocodile* it had been reduced in the proportion 1·6 to 1. Without bilge keels the *Revenge* was inferior, so far as N and E are concerned, to all the big vessels previously tested; with keels she is far superior to all. The ratio of her maximum rolling of clisity to that of the *Suffren* was 1·52 to 1, now it has become 0·55 to 1.

The importance of such results can only be properly appreciated by those who are thoroughly acquainted with the importance and difficulty of the questions of stability and nautical qualities for large armoured battleships. We shall now discuss them briefly.

We must note first that the low value of N and the high value of E in the case of the *Revenge*, while without keels, did not originate in a low value of the moment of resistance M. We shall see, on the contrary, that the hull of the *Revenge* offers by itself great resistance to rolling. The bad qualities which were revealed in the first run of the *Resolution* were caused solely by the high value of the moment of inertia which appears in the expression for E.

$$E = \sqrt{\frac{43\,\Sigma m r^2}{M_1}} \qquad (16)$$

The high value of $\Sigma m r^2$ arises from the increase in the thickness of armour since the date of the construction of the *Suffren*.

With respect to the size of the bilge keels which have so radically altered the sea-going qualities of the *Revenge*, they were one and a half times less than on the

Crocodile, if the relative sizes of the vessels be considered. This will be seen by referring to formulæ (14) and (15), whence the numerical calculation gives—

Crocodile ... ... $\frac{l\,m^4}{s\,d^3} = 105$;

Revenge ... ... $\frac{l\,m^4}{s\,d^3} = 157$.

The great reduction obtained in N arises from the extraordinarily great value attained by the co-efficient of resistance when one deals with a large battleship instead of with a small gunboat.

The application to the trials of the *Revenge* of the formulæ for period and for clisity

$$\Sigma\, m\, r^2 = \left(\frac{T_{\prime\prime}}{\pi}\right)^2 P\,(s-a)\,; \tag{17}$$

$$M_1 = 43\,N\,\Sigma\, m\, r^2\,; \tag{16a}$$

gives, for the vessel with and without keels,

$$M_1 = 133{\cdot}200 \text{ without keels,}$$
$$M_1 + \Delta M_1 = 1{,}021{\cdot}100 \text{ with keels,}$$
$$\Delta M_1 = 887{\cdot}900 \text{ effect of keels;}$$

and applying these figures to expressions of the form (14) and (15), co-efficients are obtained which differ entirely from those which were suitable for the *Crocodile*, namely,

$$M_1 = 0{\cdot}00387\; l\, m^4\,; \tag{14a}$$

$$\Delta M_1 = 4{\cdot}975\; s\, d^3. \tag{15a}$$

The co-efficient of resistance of 4·97 tons per square meter for the bilge keels is more than ten times as great as had been foreseen, and does not appear to have been attained on the *Crocodile*. This proportion is practically the same as was described by Sir William White with reference to his own expectations. The co-efficient of resistance should have been 1·6 lb. according to the experiments of Mr. Froude, but it was 16 lbs. according to the trials of the *Revenge*.

The effect produced at sea by this enormous increase of the moment of resistance is very much higher than could have been anticipated from the accepted laws of hydrodynamics.

The results were confirmed for the first time, as Sir William White has pointed out, during the cruise of the *Resolution* without bilge keels in consort with the *Repulse*, which was fitted with keels.

Upon a swell having from 5 to 6 seconds for a half period (this is a relative period taken, no doubt, with reference to the ship while in motion) the maximum inclination observed was 23° for the *Resolution*, and 11° for the *Repulse*. The half

period of rolling ought to be 8 seconds for the *Resolution*, and 8·4 seconds for the *Repulse;* this was, however, a case of rolling upon a non-synchronous swell.

The two values of $(m - 1)$ for the two vessels differ considerably, according to whether T is supposed equal to 5 seconds or to 6 seconds, and are all four equal to, or of less value than, unity.

The limit $(m - 1) = 3$, beyond which the method of calculation did not seem applicable, has therefore been passed altogether.

We can expect from the observed result, not indeed a confirmation of this method, but still a proof that the resistance of the hull exercises a sensible influence upon the amplitude of the summit roll at very low values of $m - 1$.

For this purpose we will suppose that the value of T has only been 5 seconds, which causes $m - 1$ to vary in the ratio 1·42 to 1 (its mean value being 0·29) when T_n changes from 8 seconds to 8·4 seconds. This hypothesis attributes the greatest share to the effect of change of period in the decrease of Φ_a; for on a swell of 6 seconds the co-efficient $(m - 1)$ would have varied only in the ratio 1·33 to 1.

In the total change of amplitude, taking the ratio

$$\frac{23}{11} = 2{\cdot}09,$$

the greatest share that we could attribute to the change of period is the effect which it would produce upon the values of ψ proportionally to $m - 1$; that is to say, 1·42. Deducting this effect, there remains for that of the change in the value of N—

$$\frac{2{\cdot}09}{1{\cdot}42} = 1{\cdot}47,$$

still a very considerable amount.

If, using the two values of N, we write—

$$\left(\frac{0{\cdot}0276}{0{\cdot}0036}\right) \gamma = 1{\cdot}47,$$

we obtain—

$$\gamma = 0{\cdot}19.$$

Now, if by means of Table VI. a curve be drawn of the values of γ as a function of $(m - 1)$, it is interesting to note that the point $\gamma = 0{\cdot}19$ for $(m - 1) = 0{\cdot}29$, given by observation, falls exactly upon the continuation of the curve obtained by calculation. That may be a mere effect of chance; but, as Sir William White has stated that the present series of experiments will be continued, we may hope soon to obtain results which, while permitting the verification of the data obtained by calculation and their correction, if needed, will at the same time enable us to complete those data, at the low values of $(m - 1)$, for which the method of calculation is not suited.

Remark upon Formula (10).

In the whole of the present paper up to this point, as well as in my paper of 1894, I have used formula (10) in order to express the inclination of the maximum roll, and this formula presupposes the law of decrease in still water given by the equation—

$$\delta\phi = N\phi^2, \tag{18}$$

which is a simplification of

$$\delta\phi = A + N\phi^2, \tag{19}$$

obtained by experiment for rolls beyond a certain amplitude.

This persistency does not arise, however, from a rooted attachment to the calculations made in 1869-70, with the help of the trial of the *Renard* in 1867, when the subject of the limit of the amplitude of rolling upon a synchronous swell was treated for the first time.

Expression (18) seems to me to be *a priori* less exact than

$$\delta\phi = N_1\phi + N_2\phi^2, \tag{20}$$

and the formula which would be obtained by a combination of (19) and (20) would be still more exact.

On the other hand, all the foregoing calculations for "clisity" and unsteadiness could be carried out by adopting any expression for $\delta\phi$, which would be in the form of a quadratic for ϕ. Only they would become much more complicated.*

For the two following reasons it does not appear to me desirable to increase in this way the difficulties of calculation, and to obscure the results. In the calculation for clisity it matters little at what inclination the formula (19) begins to be exact. The maximum value of Φ has only to be considered, and for this value the constant A, which makes the formula (18) accurate, appears always negligible when accompanied by the term $N\phi^2$, which is equal to the inclination Θ of the waves.

In the calculation of unsteadiness, one must take account, it is true, of the low values of ϕ for which the equations (18) and (19) are neither of them perfectly applicable, but the uncertainty arising from this cause is always less than the uncertainty as to the accuracy of the expression (4).

The results of the trials of the *Revenge*, shown in the curves of $\delta\phi$, as a function of ϕ^2 given in Fig. 4, do not nullify the preceding remarks.

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* The expression (10) for Φ might be replaced by—

$$\Phi = \frac{N_1}{2N_2} \pm \sqrt{\left(\frac{N}{2N_2}\right)^2 + \frac{\Theta}{N_2} - \frac{A}{N_2}},$$

which would seriously complicate formula (13).

I will conclude with a few short remarks upon the nature of the resistances which may be specially represented by the term $N_1 \phi$ in (20) and by the constant A in (19).

On Wave-making Power.

I have attributed to the term $N_1 \phi$ in expression (20) the duty of representing the action of the wave-making power of the water, in addition to the obvious purport of this term in a purely empirical expression.

I have already expressed my views on wave-making power.

The resistance of water upon a hull, in any movement whatsoever, has two components—one normal and the other tangential. The equal and opposite reaction of the hull upon the water gives rise to two like forces; going ahead, the normal reaction of the hull appears to be principally *wave-making*, and the tangential reaction appears to be principally *eddy-making*.

The motion of the water in opening a passage for a solid body is of a kind which produces the least resistance. The property of wave-*making* does not therefore require a special term for resistance to be added to the others, but rather gives rise to a negative correction.

In experiments on rolling in still water, while the decrease of swing is being measured, the vessel is certainly surrounded with water put into oscillation during the first period when the men are ordered to run across the deck. I have always thought this condition was a cause of the decrease in the value of N, and I have corroborated it by experiments in the tests for decrease of rolling which were made on the *Navette* while in motion. The experiments carried out on the *Revenge*, whilst in motion, confirm this result; they give, according to the curves in Fig. 4,

	N.
Revenge, without speed	0·022
,, going at 10 knots	0·032
,, ,, 12 ,, ...	0·043

If there be a difference of opinion upon the meaning of these results, the disagreement is simply verbal on the *wave-making power*. If there be a difference of opinion about the facts, an experiment of another kind will easily clear it away.

It would suffice to fire two Whitehead torpedoes at different depths from the surface, but with all the other conditions exactly the same. The immersion governor might be regulated in one case for a depth of, say, 30 ft., and in the other case for a depth of 0·3 ft. The resistance of the water would not be at all *wave-making* in the first case, and would be entirely *wave-making* in the second case. Observations on the speeds would show in which of the two cases the resistance was the greater. As for the

keels, the experiments with the *Revenge* prove that a great immersion makes them more resistant.

Returning to the consideration of rolling, if the importance given to the term involving ϕ by the consideration of *wave-making power* be put aside, we would be left with the forces which have already been described; the normal resistance is approximately proportional to ϕ^2; the tangential resistance is, moreover, proportional to ϕ; there is no theoretical reason why the term involving ϕ^2 should not preponderate.

Resistance due to Viscosity.

The presence in the expression for decrease of amplitude $\delta\phi$ of a term A, which is almost, or even quite, constant, is explained by the action of viscosity which is not present in the case of propulsion.

A ship when rolling moves a certain mass of water which has no appreciable speed $\frac{d\phi}{dt}$ relatively to the vessel; this is specially true in the case of the liquid ballast on board. This water develops a certain amount of molecular work sensibly proportional to the deformation ϕ, and depending but little on the velocity with which the deformation takes place.

Work of resistance, of this kind, compensating work of the couple stability, proportional to $\phi\,\delta\phi$, produces a reduction of amplitude $\delta\phi$ independent of ϕ.

If expression (19) exactly represented the law of decrease, and especially if it represented this law in the neighbourhood of the origin of the co-ordinates, it would be easy to find a theoretical value of A, which would be

$$A = 114{\cdot}7\,\frac{k\,p}{P\,(s-a)}, \tag{21}$$

k being the work of resistance of viscosity for a cubic metre (35·32 cubic feet) of water inclined at 1°; p the weight of the water displaced in metric tons; 114·7 a constant equal to the quotient of 2 divided by the length of the arc of 1°.

The experiments of Mr. Watts on the efficiency of liquid ballast, as a means of suppressing slight rolling, are described in the interesting paper which will be found in Vol. XXVI. of 1885, of the Transactions of the Institution of Naval Architects, and these afford a means of verifying at the same time the fact that, the term A represents the effect of viscosity, and also that the liquid ballast acts by its resistance due to viscosity.

The curves of Fig. 11 (Plate IV., Vol. XXVI.) in the paper by Mr. Watts, after having been altered by taking ϕ^2 as a variable, are shown in Fig. 5 (Plate VI. of the present Vol.). These curves satisfy the expression (19) with unusual precision.

The values of the two co-efficients A and N are as follow:—

	Weight of water ballast in metric tons.	A.	N.
No tank	—	0·08	0·0181
A small tank	43·0	0·47	0·0186
A moderate tank ...	78·8	1·26	0·0187
A large tank	135·2	2·08	0·0187
Two large tanks ...	270·4	3·56	0·0195

This Table shows that the liquid ballast acts almost solely upon the constant A, which rises in value in the ratio 1 to 44, while N does not vary the tenth part of its value.

The existence of a maximum resistance of the water ballast, for a certain predetermined height of water in the tanks, which was pointed out by Mr. Watts, proves that the work is due to a deformation of the liquid.

The increase in the value of A after the addition of bilge keels, a point observed afresh in the experiments on the *Revenge*, would seem to indicate that the keels draw behind them a certain volume of water which acts by deformation.

Conclusion.

The fact which stands out most clearly, from all the calculations, from all the experiments, and above all from the comparison between the results of calculation and those of experiment, is that of the increasing importance of the part played, on the one hand, by the resistance of water in the determination of the amplitude of rolling, and, on the other hand, the efficacy, which is very much greater than was at first supposed, of the different means by which this resistance may be increased.

The results become more and more favourable the larger the vessels which are dealt with.

In the future a more and more extended use will no doubt be made of bilge keels, of water ballast, and generally of all means for increasing the resistance, such means have been somewhat despised for a long time, but they are the only acceptable methods of reducing the amplitude of rolling in battleships, for, in such vessels, the length T_n of the period cannot be arbitrarily dealt with owing to the exigencies of stability.

For large merchant vessels the increase of the period T_n and the decrease of the co-efficient $(m - 1)$ which arises from it will, in many cases, give satisfactory results.

SEMI-AMPLITUDES Ψ OF ROLLS WITHOUT RESISTANCE, AND ϕ WITH RESISTANCE, CALCULATED AS A FUNCTION OF m, THE CO-EFFICIENT OF AGREEMENT OF THE PERIODS, AND OF N, THE CO-EFFICIENT OF DECREASE OF AMPLITUDE IN CALM WATER, FOR AN INCLINATION OF THE SLOPE OF THE WAVES OF 10°.

The numbers in italics give the amplitude of the apogee roll Φ_a of each series.

Numbers of Rolls.	$\Delta\psi$	Ψ	$m = 2$. ϕ for N=0·004	N=0·008	N=0·010	N=0·012	N=0·025	N=0·04	N=0·048
1	0	0	0	0	0	0	0	0	0
2	5·00	5·00	4·905	4·814	4·772	4·731	4·495	4·270	4·166
3	5·00	*10·00*	*9·540*	*9·143*	*8·967*	*8·800*	7·925	7·197	*6·888*
4	0	*10·00*	*9·200*	8·556	8·281	8·027	6·777	5·835	5·458
5	−5·00	5·00	4·131	3·461	3·180	2·923	1·725	0·808	0·448
6	−5·00	0							
7									
8									
9									
10									
No. of Rolls		6	5·820	5·680	5·640	5·590	5·365	5·180	5·110

			$m = 4$.						
1	0	0	0	0	0	0	0	0	0
2	2·50	2·50	2·475	2·455	2·441	2·437	2·360	2·290	2·198
3	5·00	7·50	7·265	7·062	6·956	6·870	6·351	5·898	5·660
4	7·50	15·00	13·980	13·175	12·814	12·495	10·888	9·663	9·145
5	7·50	22·50	19·900	18·062	17·316	16·660	13·698	*11·693*	*10·921*
6	5·00	27·50	22·816	*19·896*	*18·785*	*17·840*	*13·881*	11·450	10·564
7	2·50	*30·00*	*23·165*	19·380	18·034	16·910	12·484	9·973	9·094
8	0	*30·00*	21·344	17·060	15·600	14·416	9·989	7·640	6·845
9	−2·50	27·50	17·730	13·163	11·725	10·574	6·449	4·375	3·691
10	−5·00	22·50	12·140	7·688	6·325	5·244	1·424		
11	−7·50	15·00	4·694	0·187					
12	−7·50	7·50							
13	−5·00	2·50							
14	−2·50	0							
15									
16									
17									
18									
No. of Rolls		14	11·450	11·030	10·840	10·450	10·215	9·875	9·745

$\Delta\psi$	Ψ	$m = 3$. ϕ for N=0·004	N=0·008	N=0·010	N=0·012	N=0·025	N=0·04	N=0·048
0	0	0	0	0	0	0	0	0
3·333	3·333	3·290	3·247	3·229	3·210	3·094	2·977	2·923
6·666	10·000	9·587	9·237	9·074	8·920	8·114	7·432	7·141
6·666	16·666	15·325	14·270	13·830	13·423	11·484	*10·053*	*9·487*
3·333	*20·000*	*17·442*	*15·637*	*14·931*	*14·304*	*11·507*	9·656	8·741
0	*20·00*	16·366	14·060	13·197	12·440	9·330	7·440	6·630
−3·333	16·666	12·415	9·937	9·049	8·288	5·296	3·594	2·894
−6·666	10·00	5·622	3·190	2·327	1·585			
−6·666	3·333							
−3·333	0							
	10	8·830	8·570	8·420	8·185	7·800	7·560	7·465

		$m = 5$.						
0	0	0	0	0	0	0	0	0
2	2	1·984	1·970	1·963	1·954	1·883	1·861	1·837
4	6	5·847	5·710	5·643	5·580	5·206	4·900	4·752
6	12	11·335	10·753	10·533	10·305	9·124	8·207	7·818
8	20	18·035	16·550	15·980	15·442	12·938	11·194	10·513
8	28	23·775	21·012	19·986	19·075	15·178	*12·715*	*11·814*
6	34	26·885	*22·840*	*21·405*	*20·185*	*15·314*	12·482	11·483
4	38	*27·795*	22·710	21·000	19·583	14·242	11·339	10·345
2	*40*	26·900	21·136	19·284	17·785	12·399	9·630	8·706
0	*40*	24·500	18·421	16·546	15·062	9·932	7·425	6·609
−2	38	20·772	14·692	12·886	11·479	6·782	4·584	3·884
−4	34	15·777	9·906	8·211	6·924	2·612	0·570	
−6	28	9·422	3·790	2·165	0·915			
−8	20	1·413						
−8	12							
−6	6							
−4	2							
−2	0							
	18	14·180	13·480	13·280	13·120	12·455	12·105	11·960

Numbers of Rolls.	$m = 6$									$m = 7$.								
	$\Delta\psi$	Ψ	ϕ for							$\Delta\psi$	Ψ	ϕ for						
			N=0·004	N=0·008	N=0·010	N=0·012	N=0·025	N=0·04	N=0·048			N=0·004	N=0·008	N=0·010	N=0·012	N=0·025	N=0·04	N=0·048
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1·66	1·66	1·648	1·638	1·634	1·628	1·596	1·562	1·545	1·42	1·42	1·412	1·404	1·401	1·396	1·373	1·347	1·334
3	3·328	4·988	4·881	4·788	4·734	4·691	4·433	4·188	4·075	2·85	4·27	4·191	4·122	4·086	4·049	3·852	3·661	3·571
4	4·996	9·984	9·513	9·121	8·934	8·754	7·877	7·144	6·976	4·28	8·55	8·200	7·893	7·762	7·626	6·932	6·335	6·078
5	6·664	16·648	15·372	14·186	13·716	13·295	11·331	9·893	9·399	5·71	14·26	13·212	12·376	12·026	11·707	10·095	8·887	8·400
6	8·332	24·980	21·800	19·495	18·590	18·817	14·446	12·235	11·444	7·14	21·40	18·920	17·168	16·457	15·834	13·006	11·100	10·384
7	8·332	33·312	21·175	23·435	22·052	20 904	16·210	*13·396*	*12·398*	8·57	29·97	24·990	21·896	20·725	19·736	15·539	12·956	11·320
8	6·664	39·976	30·190	*25·062*	*23·290*	*21·835*	*16·262*	13·143	12·069	8·57	38·54	29·970	25·325	23·687	22·325	*16·937*	*13·850*	*12·676*
9	4·996	44·972	*31·275*	25·040	23·00	21·358	15·360	12·192	11·124	7·14	45·68	32·807	*26·743*	*24·716*	*23·082*	16·920	13·596	12·416
10	3·328	48·300	30·806	23·816	21·648	19·917	13·875	10·829	9·821	5·71	51·39	*33·917*	26·726	24·449	22·645	16·128	12·774	11·632
11	1·66	*50·00*	29·080	21·706	19·500	17·775	11·959	9·145	8·405	4·28	55·67	33·662	25·730	23·300	21·417	14·876	11·637	10·559
12	0	*50·00*	26·312	18·865	16·707	15·054	9·638	7·117	6·424	2·85	58·52	32·332	23·982	21·520	19·638	13·302	10·271	9·277
13	– 1·66	48·300	22·610	15·314	13·280	11·741	6·816	4·610	4·030	1·42	*60·00*	30·122	21·646	19·239	17·417	11·446	8·679	7·787
14	– 3·328	44·972	17·987	11·005	9·120	7·690	3·227	1·224	0·679	0	*60·00*	27·170	18·813	16·510	14·791	9·289	6·819	5·248
15	– 4·996	39·976	12·380	5·750	3·953	2·620				– 1·42	58·52	23·534	15·468	13·315	11·724	6·735	4·563	3·304
16	– 6·664	33·312	5·590							– 2·85	55·67	19·206	11·550	9·551	8·084	3·567	1·612	1·364
17	– 8·332	24·980								– 4 28	51·39	16·665	6·877	5·010	3·646			
18	– 8·332	16·648								– 5·71	45·68	10·513	1·156					
19	– 6·664	9·984								– 7·14	38·54	3·327						
20	– 4·996	4·988								– 8·57	29·97							
21	– 3·328	1·66								– 8·57	21·40							
22	– 1·66	0								– 7·14	14·26							
23										– 5·71	8·55							
24										– 4 28	4·27							
25										– 2·85	1·42							
26										– 1·42	0							
No. of Rolls		22	16·675	15·865	15·600	15·405	14·655	14·275	14·155		26	19·390	18·165	17·880	17·640	16·840	16·400	16·340

Numbers of Rolls.	$m = 8$.									$m = 9$.								
	$\Delta\psi$	Ψ	ϕ for							$\Delta\psi$	Ψ	ϕ for						
			N=0·004	N=0·008	N=0·010	N=0·012	N=0·025	N=0·04	N=0·048			N=0·004	N=0·008	N=0·010	N=0·012	N=0·025	N=0·04	N=0·048
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1·250	1·25	1·244	1·237	1·235	1·231	1·21	1·193	1·183	1·10	1·10	1·10	1·09	1·09	1·09	1·08	1·06	1·05
3	2·50	3·75	3·689	3·631	3·605	3·578	3·42	3·266	3·193	2·22	3·32	3·27	3·23	3·21	3·18	3·06	2·93	2·87
4	3·75	7·50	7·227	6·991	6·884	6·779	6·21	5·712	5·494	3·33	6·65	6·44	6·24	6·16	6·07	5·60	5·18	5·00
5	5·00	12·50	11·682	11·020	10·732	10·459	9·13	8·091	7·670	4·44	11·09	10·44	9·90	9·66	9·44	8·31	7·42	7·05
6	6·25	18·75	16·802	15·375	14·798	14·270	11·86	10·188	9·545	5·55	16·64	15·08	13·90	13·41	12·97	10·90	9·47	8·85
7	7·50	26·25	22·312	19·750	18·783	17·916	14·27	11·963	11·115	6·66	23·30	20·13	17·98	17·14	16·40	13·20	11·16	10·36
8	8·75	35·00	27·940	23·936	22·481	21·249	16·34	13·463	12·491	7·78	31·08	25·34	21·91	20·65	19·58	15·20	12·59	11·64
9	8·75	43·75	32·470	26·895	25·051	23·417	*17·47*	*14·175*	*13·057*	8·89	39·97	30·50	25·57	23·85	22·43	16·93	13·83	12·74
10	7·50	51·25	35·055	*28·082*	*25·865*	*24·001*	17·40	13·922	12·751	8·89	48·86	34·60	28·13	25·99	24·26	*17·85*	*14·41*	*13·23*
11	6·25	57·50	*36·087*	28·041	25·574	23·583	16·69	13·200	12·197	7·78	56·63	36·93	*29·12*	*26·66*	*24·71*	17·76	14·16	12·95
12	5·00	62·50	35·925	27·145	24·548	22·501	15·60	12·242	11·188	6·66	63·30	*37·86*	29·04	26·37	24·33	17·11	13·52	12·32
13	3·75	66·25	34·825	25·630	23·001	20·972	14·26	11·071	10·070	5·55	68·85	37·72	28·22	25·45	23·35	16·14	12·66	11·51
14	2·50	68·75	32·975	23·663	21·098	19·096	12·72	9·751	8·829	4·44	73·29	36·76	26·89	24·09	21·99	14·98	11·66	10·58
15	1·25	*70·00*	30·500	21·290	18·802	16·916	10·96	8·363	7·430	3·33	76·62	35·15	25·16	22·40	20·35	13·65	10·54	9·54
16	0	*70·00*	27·606	18·542	16·196	14·417	8·96	6·613	5·933	2·22	78·83	33·01	23·10	20·43	18·47	12·16	9·30	8·38
17	—1·25	68·75	24·043	15·387	13·201	11·567	6·61	4·538	3·938	1·10	*80*	30·41	20·76	18·22	16·36	10·51	7·90	7·08
18	—2·50	66·25	19·950	11·780	9·750	8·250	3·76	1·896	1·350	0	*80*	27·41	18·13	15·74	14·01	8·64	6·31	5·58
19	—3·75	62·50	15·270	7·565	5·70	4·29				—1·10	78·83	24·00	15·18	12·96	11·36	6·49	4·42	3·79
20	—5·00	57·50	9·880	2·52	0·69					—2·22	76·62	20·16	11·85	9·78	8·31	3·89	2·04	1·47
21	—6·25	51·25	3·700							—3·33	73·29	15·83	8·01	6·09	4·71	0·56		
22	—7·50	43·75								—4·44	68·85	10·92	3·48	1·62	0·27			
23	—8·75	35·00								—5·55	63·30	5·28						
24	—8·75	26·25								—6·66	56·63							
25	—7·50	18·75								—7·78	48·86							
26	—6·25	12·50								—8·89	39·97							
27	—5·00	7·50								—8·89	31·08							
28	—3·75	3·75								—7·78	23·30							
29	—2·50	1·25								—6·66	16·64							
30	—1·25	0								—5·55	11·09							
31										—4·44	6·65							
32										—3·33	3·32							
33										—2·22	1·10							
34										—1·10	0							
35										0								
No. of Rolls.		30	21·50	20·41	20·11	19·85	19·01	18·52	18·38		34	23·80	22·64	22·31	22·05	21·16	20·63	20·36

Numbers of Rolls.	$\Delta\psi$	Ψ	$m = 10$						
			ϕ for						
			N = 0·004	N = 0·08	N = 0·010	N = 0·012	N = 0·025	N = 0·04	N = 0·048
1	1·00	1·00	1·00	0 99	0 99	0·99	0 98	0·96	0·96
2	2·00	3·00	2 96	2·92	2·91	2·89	2·78	2·68	2·63
3	3·00	6·00	5·83	5·67	5·59	5·53	5·14	4·77	4·61
4	4·00	10·00	9 47	9·02	8·82	8·63	7·67	6·88	6·55
5	5·00	15·00	13·71	12·72	12 30	11·92	10·11	8·79	8·27
6	6·00	21·00	18·36	16 53	15 80	15·16	12·32	10·43	9·73
7	7·00	28·00	23·21	20·25	19·30	18·19	14·24	11·83	10·96
8	8·00	36 00	28·06	23 74	22·32	20·93	15·91	13·04	12·02
9	9·00	45·00	32·76	26·94	25·05	23·37	17·37	14·09	12·96
10	9·00	54 00	36 45	28·97	26·84	24·92	*18 14*	*14·58*	*13·37*
11	8·00	62·00	38·52	29·85	*27·36*	*25·26*	18·02	14 35	13·12
12	7·00	69 00	*39·33*	29 76	27·04	24 85	17 43	13·77	12·55
13	6·00	75 00	39·19	29·02	26·19	23·96	16·57	13·00	11·83
14	5.00	80·00	38·27	27 83	24·96	22·75	15·53	12·12	11·01
15	4·00	84 00	36·84	26·29	23·46	21·30	14·37	11·15	10·11
16	3·00	87·00	34 95	24·49	21·73	19·66	13 09	10·08	9·12
17	2·00	89 00	32·68	22·46	19 81	17 84	11·68	8 91	8·20
18	1·00	*90·00*	30 06	20 20	17·68	15·85	10·12	7·60	6 91
19	0	*90·00*	27·12	17·69	15·33	13·63	8·37	6·11	5·47
20	—1·00	89·00	23·85	14·91	12 71	11·14	6·36	4·35	3·78
21	—2·00	87·00	19·34	11·80	9·76	8 31	3 96	2·16	1·65
22	—3·00	84 00	14·50	8 25	6·35	5·01	0·94		
23	—4·00	80·00	9·16	4 12	2·30	1·00			
24	—5·00	75·00	3·12						
25	—6·00	69·00							
26	—7·00	62·00							
27	—8·00	54·00							
28	—9·00	45·00							
29	—9·00	36 00							
30	—8·00	28·00							
31	—7·00	21·00							
32	—6·00	15·00							
33	—5·00	10·00							
34	—4·00	6·00							
35	—3·00	3·00							
36	—2·00	1·00							
37	—1·00	0							
38	0								
Number of Rolls		38	25·45	24·83	24·47	24·20	23·23	22·73	22·60

DISCUSSION.

Sir William White, K.C.B., LL.D., F.R.S. (Vice-President): This is a paper which is of the greatest importance and interest to everyone. There are certain leading ideas in the paper which I am sure will commend themselves to all acquainted with the subject. These seem to me to be the broad conclusions which all of us, who have been attempting for the last twenty or thirty years to deal with the behaviour of ships at sea, have quite agreed on—first of all, that it is impossible, apart from direct experiment on the oscillation of ships in still water, and the consequent determination of their resistance to rolling, to do anything that is of much practical value in relation to the behaviour of ships at sea; and, secondly, that though, for mathematical purposes, we may very reasonably assume certain hypothetical conditions in regard to the uniformity of wave motion, and the probable effect of resistance, yet, in practice, we can only deal with these matters by associating the results of rolling experiments in still water with graphic processes of integration, which can be applied to variations in the character and dimensions of successive waves, in cases that do not admit of being solved by direct mathematical processes. I think Monsieur Bertin will agree that these are the broad conclusions of the paper. Monsieur Bertin goes on to illustrate what, in recent cases, has come out most prominently, namely, that in the actual behaviour of ships at sea, fluid resistance plays a much more important part than had been previously supposed. He has alluded most kindly to a paper which I contributed to the Spring Meeting of the Institution. That paper was given under circumstances of extreme personal difficulty, but it dealt with matters of such great importance and such wide-reaching purpose and effect, that it seemed to me to be well to put the facts on record, at the earliest possible moment, for the consideration of the members of the Institution. It is the greatest satisfaction to me that already so competent an authority as Monsieur Bertin has begun to analyse, to interpret, and to apply in a wider way, the results that I was then able to place at the disposal of the members. We all know in this Institution how well qualified Monsieur Bertin is to deal with these matters. In England we think of the late Mr. Froude as the leader of thought in relation to these subjects. In France there are many authorities who have written ably upon this point; and I think I shall speak the feeling, not merely of our English members, but of the French members of the Institution, and of all interested in naval architecture, when I say that Monsieur Bertin is a worthy colleague and co-worker with his English brethren. There are certain tables in the paper which can be followed even by those who do not possess the mathematical knowledge to understand the process. The table on page 5, for example, taken broadly, shows this, viz.: that in the theoretical case of synchronism of motion between the ship and the waves, apart from resistance, a ship must be overturned in the passage of a very few waves; yet, by the introduction of a very low value in the co-efficient of resistance in the table headed Φ, the amplitude of oscillation, instead of being infinite, comes down to 50°, and then, by a change in the co-efficient, from 0·004 to 0·036, the amplitude of oscillation is reduced to only one-third. Results such as these may be only illustrative, and may not be exact; but it shows that we have yet much to learn with regard to the means of increasing the resistance to rolling, and the possibility of steadying ships by such means. Monsieur Bertin has frankly stated his agreement with the position I have taken up in the paper to which I referred. I then said that, no one could have foreseen from past experiments such results as we attained in the experiments on H.M.S. *Revenge*, and Monsieur Bertin absolutely confirms that conviction. We must all feel that in this matter we are by no means at the end of our knowledge, and if, as I trust may be the case, our English experiments on bilge keels and their resistance, are supplemented in France by a

continuation of those valuable experiments which have been made here for years on the oscillation of ships in still water, we shall, at some future meeting of the Institution, find Monsieur Bertin, or some equally competent authority, coming forward, and, on the basis of ascertained facts, giving us a most valuable extension of theory.

Mr. B. Martell (Vice-President): Mr. President and gentlemen, I have very much pleasure in proposing a vote of thanks to Monsieur Bertin for the very interesting paper which he has contributed. We are greatly indebted to him for coming forward and giving us the results of his valuable experiments so quickly as he has done. There is much more liberality now shown in all the great departments of governments in furnishing information which is obtained through experiments such as these. With reference to the remarks made here as to the great effects produced by the fitting of bilge keels to the Government ships, as I understand the case, Sir William White, when he designed those ships, had some idea that although bilge keels were very efficacious with regard to ships of moderate size in preventing undue rolling, yet in such enormous ships, as they were then designing, the effect could not be determined upon sufficiently to justify him in recommending the fitting of them, in view of the risk which would be incurred in docking those ships and other causes. It has been very highly gratifying to find such a beneficial effect produced that the rolling, by fitting those keels in such large ships, has been reduced to about one-half. I think we are greatly indebted to Sir William White for coming forward as he did, and frankly placing before the members of this Institution the result of the adoption which he made, with reference to the fitting of those keels. We have had some very great experience of those in the Mercantile Marine for a number of years. We knew that the effect of rolling could be considerably diminished by the fitting of those keels, but there was very great doubt, indeed, whether in such enormous structures as large ironclads the same effects could be produced. I am happy, so far as experiments have gone, to have found that such is the case, and I am sure we all look forward to the extended information that Monsieur Bertin will supply us with as the result of the further experiments he is now carrying on. I have very great pleasure in proposing a vote of thanks to Monsieur Bertin for his paper, which I am sure you will very cordially respond to.

The President (the Right Hon. Lord Brassey, K.C.B.): Gentlemen, I gather that it is your unanimous wish that the best thanks of the Institution be given to Monsieur Bertin for his valuable paper.

ON WOOD AND COPPER SHEATHING FOR STEEL SHIPS.

By Sir William White, K.C.B., LL.D., F.R.S., Director of Naval Construction, and Assistant-Controller of the Navy, Vice-President.

[Read at the Summer Meetings of the Thirty-sixth Session of the Institution of Naval Architects, June 11, 1895; the Right Hon. Lord Brassey, K.C.B., President, in the Chair.]

The subject with which this paper deals was suggested to me as likely to prove of interest and value to the members of the Institution. Nearly twenty-five years have elapsed since the sheathing of iron and steel ships was last discussed in papers published in our Transactions. During this period much experience has been gained, new methods of sheathing have been introduced, and at the present time larger numbers of sheathed cruisers are being built for various navies than at any previous date.

A paper contributed by the late Mr. Grantham to the Transactions for 1869 contains an excellent summary of the state of knowledge in regard to methods of sheathing, and the results anticipated at that time. On reference thereto it will be seen that practically no experience had been obtained with sheathed ships; and that arguments were chiefly based upon experience gained with composite ships of the Mercantile Marine. In the Royal Navy wood had been largely—indeed, chiefly—used in the construction of various classes of unarmoured vessels. But new departures had been made a short time previously. For the smaller classes of cruisers, up to corvettes, the composite system had been adopted, the internal portions of the framing and structure being of iron, and the skin being of wood. For the larger and swifter cruisers (*Inconstant* and *Volage* classes), where the composite system did not provide sufficient strength and rigidity, complete iron hulls had been associated with external wood and copper sheathing. The object proposed was the same in all cases, viz., to secure the power of keeping the sea for long periods without such serious fouling of the bottoms, and consequent loss of speed, as were commonly experienced with iron or steel ships. For composite ships it was possible to proceed with certainty on the basis of mercantile experience. For sheathed ships the procedure was necessarily experimental to a large extent.

The Transactions for the period under review also indicate a considerable divergence of opinion as to the best metallic sheathing to be used on iron and steel ships.

There were advocates of copper as an unrivalled anti-fouling material, resting their support on the extended experience of all war-fleets. On the other hand, the champions of zinc dwelt upon the danger of galvanic action being set up between copper sheathing and iron hulls, leading to serious injury to the latter. Their contention was that, with suitable arrangements, zinc could be made to keep fairly free from fouling when immersed in sea water for long periods, and that its position relatively to iron in the electrical scale made its use on iron or steel hulls absolutely safe. The latter statement was undoubtedly correct; but from the first there were those who pointed out that the action of sea water on zinc produced insoluble salts which must cause serious roughness on the surface, and would probably lead to serious fouling under many conditions of service.

It will suffice to state, in passing, that experience with zinc-sheathed ships during the last twenty years has confirmed the anticipations adverse to the anti-fouling properties of zinc. In the Royal Navy it has become the rule to dock and paint the bottoms of such ships just as is done with iron ships. After long periods afloat, zinc-sheathed ships usually have an advantage over unsheathed iron or steel ships in regard to fouling; and certainly they are less liable to corrosion of the skin plating. But the general conclusion, reached by all who have tried both zinc and copper sheathing, is that the additional first cost involved in using the latter is amply repaid on subsequent service by economy of coal and maintenance of speed.

Mr. Grantham claimed, apparently with justice, to have been the first to propose the use of wood and copper sheathing on iron ships, in association with brass stems and stern-posts. In his paper of 1869 he dealt very thoroughly with the allegation that serious galvanic action would probably be set up on iron hulls if copper sheathing were fitted; and quoted in support of his views the great authority of Mr. Mallet. On the whole, the conclusions arrived at by Mr. Grantham on this part of the subject are fairly in accord with subsequent experience, and the fact deserves to be noted, more especially as it must be pointed out that, in other respects, his anticipations have not been realised.

The primary purpose of the system of sheathing proposed by Mr. Grantham (see Figs. 1 and 2, Plate VII.) was to secure the anti-fouling properties of coppered bottoms, with a minimum risk of metallic connection being made between the copper sheathing and the iron skin, so that the latter might not suffer from galvanic action if sea water found its way behind the wood planking fitted between the copper and the iron hull. For this purpose the wood planking was fitted in two thicknesses. The inner (next the iron skin) was fitted between Z-bar frames riveted to the skin, and kept in place chiefly by means of wood wedges, with the additional security of a few iron screw bolts passing through the skin, having nuts hove up on its inner surface. The outer layer of wood was secured to the inner layer by brass screw bolts, passing into (but not intended

to pass through) the inner layer. Both layers of wood were to be well caulked, and the "faying" surfaces were to be well bedded in paint or composition.

Mr. Grantham attached great importance to the use of the minimum number of bolts in the inner thickness of wood. From his lengthy remarks on this head it would appear that his chief objection to bolts was their assumed tendency to rapid and serious corrosion, produced by the entry of water into the bolt holes, as the result of "working" or movement in the planking when a sheathed ship was subjected to severe stresses at sea. That such bolts, if of iron, may became seriously corroded is undoubted; but hardly in the manner, or for the reasons, supposed by Mr. Grantham. In fact, if such "working" of the wood planking took place as he presumed, it would probably involve consequences of a much more serious character than mere corrosion of bolt fastenings.

In the Russian Navy, I believe, considerable use has been made of Mr. Grantham's system of sheathing, and it would be of interest to know the results of that experience. Perhaps they may be communicated hereafter by some of our Russian members.

The earliest sheathed ship in the Royal Navy was the swift cruiser *Inconstant* designed in 1866, and launched in 1868. Her arrangements are illustrated in Figs. 3 and 4, Plate VIII. They were of a very special and costly nature, and have never been repeated. Thick external strips of iron were riveted to the skin plating: the spaces between the strips were made flush with teak "filling pieces." Into these strips were screwed the points of the iron bolts which secured the inner thickness of wood. The outer thickness of wood was fastened with brass screw bolts passing into, but not through the inner thickness. In this manner direct metallic connection between the copper sheathing and the iron hull was avoided, while the iron skin was unpierced by the bolts securing the inner layer of wood. The wood planking had the faying surfaces bedded in waterproof glue, and was carefully caulked throughout.

This ship has now been afloat for twenty-seven years, and has performed much trying service under sail and steam. At the date of her design she was of remarkable speed, with exceptionally large engine power. Her sheathing has never given serious trouble, and the anti-fouling properties of her coppered bottom have been well secured.

Soon after the *Inconstant* was designed, two smaller sheathed vessels, the *Volage* and *Active*, were laid down, and were launched in 1869. They remain in service after being twenty-six years afloat. From 1885 onwards they have been continuously employed in the training squadron. Throughout their service no serious trouble has occurred with their sheathing or its fastenings. A departure was made from the system followed in the *Inconstant* in regard to the mode of fastening the inner thickness of planking. Instead of elaborate and heavy arrangements for avoiding through bolts, the

simple plan was followed of securing the planks directly to the skin plating by iron bolts, screwed through the skin, with nuts hove up on the inside. Both layers of planking were worked longitudinally, the edges and butts of adjacent planks in the two layers being carefully "shifted," in order to distribute the fastenings satisfactorily, and to develop the full strength of the combination. The outer layer of planking was secured to the inner by metal screws similar to those used in the *Inconstant*.

In the paper of 1869, above mentioned, Mr. Grantham strongly condemned this system of through-bolting, and predicted failure through serious corrosion of the bolts. Experience has not justified his opinion, although there have been many cases where bolts have corroded in sheathed vessels. The simplification gained by through fastenings led to the general adoption of this method of sheathing in the Royal Navy for a period of twenty years (1868-1887), during which time twenty-four ships of various classes and sizes were constructed with wood and copper sheathing, and eight with zinc sheathing. Very similar arrangements were followed in sheathed ships built for foreign navies. Figs. 5 and 6, Plate IX. illustrate the principal features of the plan.

Speaking broadly, it may be said that for copper-bottomed vessels up to 2,000 tons displacement the practice of the Royal Navy during this period was to adopt the "composite" system, the skin consisting of two layers of planking disposed as in Fig. 5, reinforced by certain iron strengthenings, in the form of sheer-strakes, keel-plates, bilge-stringers, &c. The inner layer of planking was secured to the frame-angles by brass bolts, screwed through the angles, with nuts on the inner ends. The outer layer was secured to the inner by through copper bolts, the points being clenched on rings inside the planking. The stems and sternposts of these composite vessels were generally of wood. Up to the limit of displacement named, this composite system proved strong and durable. Vessels have remained on active service over twenty years.

For ships of greater dimensions with coppered bottoms the system of sheathing illustrated by Figs. 5 and 6 was practically adhered to until 1887. In some cases the stems and sternposts were of wood, but more commonly of gun-metal or bronze. The thicknesses of wood in the two layers of planking and the dimensions of the bolts were practically constant for all classes of ships. The thicknesses of skin plating were varied, of course, with the size of the ship. For purposes of structural strength the wood planking was practically neglected in determining scantlings, except that the skin plating was made a little thinner or the frame spacing a little wider than it would have been in an unsheathed ship of the same dimensions. The largest ships sheathed on this system in the Royal Navy are the *Impérieuse* and *Warspite*, of about 8,400 tons, built specially for service on distant stations, where facilities for docking are limited or non-existent.

The fundamental idea in this method of sheathing, as above explained, was the avoidance of metallic connection between the copper sheathing and the iron or steel hull, and the consequent prevention of galvanic action on the skin plating. It was hoped also that with the precautions ordered to be taken, with good workmanship and thorough caulking, the two thicknesses of wood sheathing would be as water-excluding as the corresponding planking necessarily had to be on composite ships. In that event, sea water should not have passed behind the wood and reached the outer surface of the skin plating, so that neither serious galvanic action nor corrosion would have occurred. To secure this result great care was ordered to be exercised in the selection of the planking. Teak was largely used and almost exclusively adopted for the inner thickness. For the outer thickness teak was specified for the parts above the light water-line, but pitch-pine and English or Canada elm were permitted to be used under water as alternatives to teak.

Experience has shown that these anticipations were not realised in practice. Careful observations, made when some of these sheathed ships were first coppered, showed that a more or less indirect metallic connection was established, and that a galvanic current passed between the copper sheathing and the iron or steel hull. Moreover, after ships sheathed on this plan have been some time afloat, water, as a rule, finds its way through the planking or the caulking, into the spaces between the planks and the skin plating. When such ships are docked, more or less considerable quantities of water usually run out from behind the sheathing, if holes are bored, or bolts removed, to facilitate its exit.

This entry of water and the degree of saturation of the sheathing varies very much in different vessels. The amount of water which enters depends upon many circumstances; such as the accurate fitting of the planks, the efficiency and distribution of the fastenings, the good bedding of the faying surfaces on paints or compositions, or the proper injection of these materials after the planks are fitted and fastened. The causes of entry also vary. Local defects in planking, inefficient arrangements for stopping the passage of water through bolt-holes, imperfect caulking, or the boring of holes for screw-bolts fastening the outer thickness of planking *completely through* the inner thickness, may all produce the same result. Whatever may be the cause, if water once finds its way behind the sheathing, from the nature of the case it may be expected gradually to find its way over large surfaces of the bottom and to lodge there for such periods as the ship remains afloat. All this points to the importance of securing the best workmanship and materials in the sheathing of steel ships, of using every means to minimise the spaces to which water can find access, and of securing the thorough watertightness of the steel skin plating.

Experience has shown that under the actual conditions of service iron and steel ships sheathed on the system illustrated by Figs. 5 and 6, maintain fairly clean bottoms

for considerable periods afloat, and suffer no serious deterioration of the hulls, especially of the skin plating, when water finds access behind the planking, or saturates it. In no case within my knowledge has galvanic action or corrosion extensively affected the skin plating or its riveting. The points of rivets have in some cases been corroded, but not to a serious extent. On the other hand, there have been many instances, both in the Royal Navy and in foreign navies, where the presence of water behind the wood sheathing has led to the comparatively rapid corrosion of large numbers of the iron bolts securing the inner thickness of wood. This corrosion usually occurs in the immediate neighbourhood of the steel bottom, and in some instances has practically eaten the bolts away, rendering them useless as fastenings. Instances have occurred in both British and foreign ships where serious deterioration of this kind has happened within four or five years of the launch ; and considerable expense has been involved in renewing the fastenings.

Having regard to the great number of the bolts in the inner thickness of planking, it is obvious that, even when the corrosion of many of the iron fastenings has taken place, no risk is involved either to the safety or structural strength of the vessel. Slight leakage may occur where bolts have been practically worn away, but this can be readily dealt with from inside the ship. With adjacent planks in the two layers overlying one another and fastened as shown in Fig. 5, there is practically no danger of detachment of planks in which corroded bolts are situated. But even if the whole wood sheathing were removed, the structural strength of the iron or steel hull would be sufficient in most cases. No such movement or working of the steel hull is conceivable under the maximum stresses occurring in practice on a well-designed ship, as would result in sensible straining or disturbance of the wood sheathing and its fastenings. All experience confirms this view.

As an example in support of this general statement reference may be made to the *Calliope*. At the end of 1888, it was discovered that serious corrosion had occurred in a considerable number of the bolts fastening many of the planks in the inner thickness of her wood sheathing. After full consideration it was decided to continue the ship on service, and to defer thorough repair until her commission was completed and she returned to England. A few months later (March, 1889), the vessel successfully encountered the fearful hurricane at Samoa which destroyed so many other vessels ; and passed through this ordeal, with her sheathing bolts in the defective condition described, without any sign of working or weakness.

It is interesting to note in passing that Mr. Mallet, whose experimental researches on corrosion are so well known, predicted that the hulls of copper-sheathed ships would suffer but little, even if water found access to their skins. In a passage quoted by Mr. Grantham, Mr. Mallet clearly explained that "unless there was a stream of water

in and out, so as constantly to renew the agents of corrosion," no serious deterioration would take place; and that if water "lodged" behind the wood sheathing it would speedily lose most of its corrosive power. Obviously the latter condition is realised very closely in ships built on the system described. Water which enters does "lodge," and suffers little change. Moreover, the paint or composition used as "bedding" for the inner layer of wood, gives considerable protection to the outer surface of the skin-plating. The bolts are not equally protected and therefore suffer more from local corrosion, which may be rapid at first, but must be slower in the later stages. It is a suggestive fact that, even on ships where corrosion of the iron bolts has been most considerable, there has been practically no loss of anti-fouling property in the copper sheathing. This in itself is a good practical proof that no serious galvanic action was in progress to the prejudice of the iron or steel hulls, although observations proved that a galvanic current was passing, as explained above.

In 1887 it became my duty to review the experience which had been gained with copper-sheathed ships, and to propose a system for future adoption in the Royal Navy. For this purpose, I placed myself in communication with the shipbuilding officers serving under the Admiralty, and with private shipbuilders in all parts of the country who had constructed composite vessels. General experience appeared to prove that, in yachts and other vessels built on the composite system with one thickness of planking and copper sheathing, no trouble had arisen when brass bolts were used to fasten the planking to the frames; whereas iron bolts had rapidly deteriorated. One case came under my notice where a foreign ship, built abroad, had been copper sheathed upon a single thickness of wood, secured by iron bolts. These had rapidly deteriorated, and had to be removed at considerable cost; on the contrary, metal bolts (used as fastenings to the sea connections) were found in perfect order, and the screw threads in the skin plating tapped to receive the points of these bolts were as clean-cut and in as good condition as when first formed. The skin plating itself had not suffered.

After full consideration, I proposed the system of sheathing illustrated by Figs. 7 and 8, Plate IX., with a single thickness of wood planking, fastened to the skin plating with bolts of naval brass, screwed through the steel skin; with nuts hove up on iron or steel plate-washers, and gromets on the inside of the bottom plating.

The principal features of this system are as follow:—

(1) The adoption of such a thickness of wood sheathing as will admit of thorough caulking. The mean finished thickness of teak accepted is 4 in. for large ships and $3\frac{1}{2}$ in. for the smaller classes.

(2) The use of naval brass bolts and nuts, with their points screwed through the skin plating, and with thin plate washers fitted underneath the nuts.

(3) The thorough water-testing of the skin plating before planking is worked.

(4) The most careful fitting, fairing, and fastening of the planks; the coating of all faying surfaces with suitable compositions before the planks are fixed in place; and the subsequent injection of composition in order to fill any interstices left between the planking and the plating.

(5) The use of hempen gromets steeped in red lead under the bolt heads and under the plate washers, to secure watertightness in the bolt-holes.

Detailed instructions for the working of sheathing on this system were drawn up by a committee of experienced shipbuilding officers, and have been found most valuable for guidance.

Thirty completed ships have been sheathed on this system since 1887, and sixteen vessels are now building. In other words, during the last seven years nearly twice as many copper-sheathed ships have been added to the Royal Navy as were added in the period 1868-1887.

My expectation was that, with the new method it would prove possible to practically exclude water from behind the wood sheathing. If water should enter in any case then the bolts would not corrode as iron bolts have done. Further, there was every reason to believe that the skin plating would not suffer from galvanic action or corrosion.

As the system was necessarily experimental to some extent, orders were given to make periodical examinations and special reports on the condition of the wood sheathing; its fastenings, and the steel skin. When ships were docked careful examinations of the outer bottom were to be made; copper and planking being removed if thought desirable.

The longest period any of these vessels has been afloat is about six years. This is only a moderate period of trial, although it exceeds by one-half the period which has sufficed to cause serious corrosion in the iron fastenings of many ships sheathed on the the earlier system. Numerous reports have been made during this period from ships employed on various stations. These reports have been uniformly satisfactory. They agree in the statement that the copper has done its work as an anti-fouler, that the wood sheathing and steel hull remain in good condition, and that the naval brass bolts have not deteriorated. In nearly all cases the spaces behind the sheathing have been found dry; and where water has been found it has been in very small quantities, occupying very limited spaces.

In one instance an adverse report was received from a ship on a foreign station at an early period in her service. She was ordered to be docked and thoroughly examined abroad. It was then shown that the defects were in no way important.

Last December, when the ship had completed her commission and had been thoroughly examined at a home Dockyard, it was reported that the wood sheathing and the skin plating were in good condition, the plating being found dry where graving pieces were cut out of the wood sheathing. The bolts were also in good order. This was five years from the date of launch.

The system has been applied to battleships of large size—the *Centurion*, *Barfleur*, and *Renown*—and to a considerable number of cruisers of high speed and large dimensions. In all these vessels, so far as experience has been gained, the plan has proved completely successful. As one typical example, the *Crescent* may be mentioned. Launched in March, 1892, she was docked and thoroughly examined in March, 1895, after two voyages from England to Australia and back, in the course of which she had steamed about 50,000 knots at an average speed of about 12½ knots. The report may be summarised:—Several pieces of wood sheathing were cut out, and some bolts removed from various parts of the bottom. In each case the skin plating was found to be quite dry, showing no sign of rust. The bolts were found as bright as when they were fitted in place, and the threads in the bolt holes were clean and free from rust. In no place had the copper ceased to serve the purpose for which it was fitted, and the ship might have remained afloat a considerably longer time without fouling taking place.

It is unnecessary to dwell upon the ease and economy of the processes of examination and repair obtained with the single thickness of wood as compared with two thicknesses worked as in Figs. 5 and 6. Roughly speaking, to remove *one* plank from the inner thickness, *four* outer planks must be disturbed. Both weight and cost of sheathing are also reduced by the single thickness.

These considerations, and the favourable experience so far gained, have led to the abandonment of the composite system in favour of the sheathed system for sloops and small vessels of the Royal Navy, which have hitherto had wood skins in two thicknesses. With the same weight it is possible to fit a complete steel skin and a single thickness of wood. Greater strength and rigidity are thus secured.

There are obvious limits to the thinness of the steel skin of small sheathed ships. It has been thought in every way desirable to retain the screwing of the bolts through the skin plating which was a feature in the earlier plans. Less than ¼ in. plating would hardly give a satisfactory hold for the screw bolts, and this is the minimum thickness accepted. By accidental blows or carelessness on the part of the workmen in heaving up the nuts, bolt-ends and nuts may be broken off. Such cases have occurred, and then the good holding of the screwed bolt-end in the plating becomes important. The same thing is true if, by external injury, planks are torn off and bolts broken. There is a better chance of the holes being filled and leakage prevented.

No doubt the minimum thickness of skin accepted for the smallest sheathed vessels might be carried on into vessels of considerable size, in association with the thickness of teak plank necessary to secure efficient caulking ($3\frac{1}{2}$ to 4 in.). Such planking obviously adds greatly to the local strength, and stiffens the bottom plating against both buckling and local deformation. Under tensile stresses also there is good reason for supposing that, within the limits of stress occurring in practice, teak planks, fitted and fastened as described, are capable of lending valuable assistance to the steel skin.

Professor Rankine proposed to treat teak as equivalent to about *one-sixteenth* its effective sectional area in steel when constructing "equivalent girders." The only experiments with which I am acquainted in which combinations of plating and planking have been subjected to tensile stress were arranged by myself, and conducted at Chatham in 1869. They were of a preliminary character only, and served chiefly as demonstrations of the great difficulty involved in obtaining satisfactory and representative results. I learned much on that occasion as to the unexpected fractures possible with wood planks, when samples were tested to destruction. They included planks of Dantzic oak, red pine, and teak bolted to iron and steel plates.

Neither the testing machine available nor the means of measuring extensions at my disposal were such as enabled precise results to be obtained. Enough was done, however, to show that Rankine's rule was not an *over-estimate* of the value of teak and other woods under tensile stresses such as are likely to be accepted in practice on the bottoms of ships. This result sufficed for the object I then had in view, and the experiments have never been resumed.

Reference is made to them now in order to emphasise the point that our established practice—which is roughly to keep the bottom plating of sheathed ships about one-sixteenth of an inch thinner than the bottom plating of unsheathed ships of the same dimensions—really and intentionally gives a margin of strength in favour of the sheathed ship. Wood planking, properly fitted and fastened, is more than a mere "padding" on which the copper sheets are nailed, although it is fitted primarily for that purpose.

While the fact is recognised that teak planking on the bottom of a sheathed ship is capable of giving valuable assistance to skin plating under tensile as well as compressive stresses such as occur in practice, no practical advantage has hitherto been taken of that fact. In small ships the thinnest bottom plating permissible gives more than the necessary structural strength without any assistance from wood planking, consequently the only reason for fitting the latter is to receive the copper sheathing. If full credit were taken for the assistance which the wood could give, within working limits of stress, in ships of large dimensions a sensible reduction might be made in the

thickness of the skin plating. For the largest ships yet sheathed this reduction might approach ¼ in. by Rankine's rule. It has been preferred, however, not to carry the reduction nearly so far. In fact, the actual thicknesses of plating used in large ships would give sufficient strength in most cases if acting alone. The reasons for this course are various. Underlying them all is the general feeling that it is preferable to treat wood sheathing as an adjunct to the structure proper, and not as a necessary contributory to the structural strength.

One consequence of this is that, sheathed ships, when compared with unsheathed, have to carry a load of wood and copper sheathing constituting a large addition to the weight of hull. If a ship of given outside form is sheathed, the additional displacement gained very nearly conterbalances the extra weight involved. This added displacement has to be driven, and, with engines of a certain horse-power, the unsheathed ship *with clean bottom* will be a little faster than the sheathed ship. This advantage speedily disappears, however, after the ships are afloat, as the bottom of the unsheathed ship is sure to foul, while that of the sheathed ship keeps clean.

The early advocates of sheathing, including Mr. Grantham, dwelt much upon the great gain resulting therefrom in case of grounding or other rough usage, which would perforate or seriously damage the thin skin plating of unsheathed ships. Cellular double bottoms were not so common a quarter of a century ago as they are now. Experience in both the war and mercantile marine has shown such bottoms to be the best possible provision against accidents of the kind. No one would now be likely to advocate as alternatives to double bottoms either a considerable thickening of the skin plating with stronger supporting frames, or the reinforcement of the skin by wood planking.

Wood planking outside an iron or steel skin does undoubtedly add to its capacity for taking hard rubs. Fairbairn's experiments made a plank 3 in. thick, about equal to an iron plate ¼ in. thick, in resistance to puncture by concentrated steady pressure. The actual gain in a sheathed ship is not fully expressed by these figures. The wood planking has a capacity for distributing local pressures and crushing under them, which is of enormous value in relieving the skin plating behind it from severe local distress. This fact has been repeatedly illustrated by accidents to sheathed ships. For example, the *Warspite*, of the Royal Navy, took the ground badly in 1892, the false keel was torn away, the main keel badly damaged, and a considerable area of the wood sheathing crushed, yet the damage to the bottom plating and framing was not very serious or difficult to repair.

For many of the services which have to be performed by the smaller classes of H.M. ships, it is most desirable to have a stout wood bottom protected by copper. Bare thin iron or steel plating is unsuitable under such conditions both to withstand the

shocks of grounding and the risks of serious and rapid corrosion in tropical waters, containing large quantities of vegetable matter. Hitherto composite ships have performed these duties ; now sheathed ships are employed.

It has always been recognised that in case of serious accident to a sheathed ship, involving the exposure of certain portions of the bottom to possible galvanic action, no time should be lost in effecting examination and necessary repairs. Hitherto no difficulty has arisen in complying with these instructions, and their importance is obvious.

There have been many advocates of plans for the electro-deposition of copper or zinc directly on the surfaces of iron and steel plating, for the purpose of preventing fouling. It is unnecessary to repeat what has been said in regard to the unsuitability of zinc as an anti-fouler. There has been a consensus of opinion among responsible authorities adverse to the deposition of copper directly upon iron or steel surfaces intended to be immersed in sea water, and necessarily subject to risks of abrasion and exposure in actual service. On this account such plans have never found favour, quite apart from any consideration of the difficulties and expense of carrying them into practical effect. Experience has shown also that care is necessary even in the use on ordinary iron or steel bottoms of anti-fouling compositions in which copper is largely used. In all war fleets up to the present time the practice is universal which interposes wood planking in one or two thicknesses between the skin plating and copper sheathing.

About fifteen years ago a thorough investigation was made at the Admiralty into the relative advantages and disadvantages of substituting a non-corrodible skin for the combination of steel and wood usually adopted in sheathed ships. Naval brass was considered the most suitable material then available for the purpose, taking into account its strength and other qualities. The conclusion reached was that it was preferable on the grounds of cost and efficiency to adhere to the use of wood and copper sheathing.

When nickel-steel, with high percentages of nickel and relatively incorrodible, was introduced, the matter was again considered, but no change was thought desirable.

The introduction of various bronzes and aluminium alloys has also drawn attention to the possibility of improvement. Many years ago an experimental torpedo-boat was built of bronze for the Royal Navy, but the experiment has not been repeated. More recently aluminium alloys and bronze have been used for yachts and small torpedo-boats in which the desire to save weight has been paramount and first cost has not been much regarded. Experience gained in these vessels will be of value, especially in regard to the steps necessary for the preservation of clean bottoms. It is understood to have been already found advantageous to paint the bottoms of

aluminium-built vessels. On this matter the discussion may afford some information, as so much has been done in France to develop the use of aluminium alloys.

When this subject was discussed in 1869 there were some, including Mr. Grantham, who thought that sheathing would be largely employed for iron ships of the Mercantile Marine as a preventive of foulness of bottom and its consequent disadvantages. These anticipations have not been realised. I am not aware of the existence of any important mercantile steamer which has wood and copper sheathing. In fact, the composite system has practically disappeared from the Mercantile Marine, and is used simply for yachts and small vessels. Facts such as these are suggestive that there must be good reasons why private shipowners have not followed the lead of war-fleets in this matter of sheathing. These reasons are not difficult to discover, and they make it most improbable that wood and copper sheathing will be adopted even for the swiftest merchant steamers. The evils of fouling in iron and steel ships are real enough. But, taking into account the great and increasing facilities for docking throughout the world, the improved anti-corrosive and anti-fouling compositions now available, and the moderate time and cost involved in cleaning and painting the bottoms of iron and steel ships, it becomes obvious that it is more economical, on the whole, to dock and clean as frequently as may be necessary to avoid serious fouling, rather than to incur the large additional cost of sheathing. Merchant ships from the nature of their employment are frequently in port; and all vessels of high speed are employed on fixed routes and regular services. Under these conditions docking twice, or thrice, or even four times, in the year is not a serious matter; while with such frequent cleaning of the bottoms fouling cannot become serious.

For warships, especially the cruiser classes, the conditions are essentially different. These vessels are built with a view to distant and uncertain services, including the necessity for keeping the sea for long periods, and being for years on stations where suitable docking accommodation may be entirely wanting, especially in war time. Economical considerations have to give way to other conditions in such vessels. Continued cleanness of bottom and maintenance of speed must be secured, even if first cost has to be largely increased in the process. This is the reason why, in recent years, the numbers of sheathed cruisers in all war-fleets have been so greatly increased.

Even copper-sheathed vessels may, and do, become foul after long periods afloat, and under certain circumstances I have seen instances in which extraordinary fouling has occurred. On the contrary, copper bottoms usually keep fairly clean for a considerable time, and I have seen copper-sheathed steel vessels docked after one and a half to two years' service, chiefly in hot climates, with practically clean bottoms.

The degree of foulness attained by unsheathed iron or steel ships necessarily varies very greatly; but it seems to be generally agreed that in high-speed ships docking and cleaning must, as a rule, take place twice or thrice a year in order to maintain speed and economy of coal. Some lines, I am informed, find it advantageous to dock their vessels four times a year on an average. In the Royal Navy unsheathed ships are docked and cleaned about twice in the year.

Even with such frequent docking and cleaning there is a sensible difference in steaming performance between clean and dirty bottoms. This, again, is a matter on which hard and fast rules cannot be laid down. Cases are on record where very serious fouling has occurred after short periods afloat; while in other instances, from causes not fully ascertained, the bottoms have remained fairly clean for a year.

Careful observations made in the Royal Navy, on ships employed in European waters, have shown that after five to six months afloat about 20 to 25 per cent. more power was required to maintain ordinary cruising speeds than sufficed with clean bottoms; after ten to twelve months afloat this increase of power became 40 to 50 per cent. The ships on which these figures are based were not considered exceptionally foul when docked.

Accepting these figures, it will be seen that for ships which, from the nature of their service, must keep the sea commonly for over a year, bare iron or steel bottoms are very disadvantageous. Under ordinary cruising conditions the coal expenditure is enormously increased, and the coal endurance correspondingly diminished. Supposing the maximum horse-power developed to remain unchanged, the maximum speed obtainable will be considerably degraded by the foul bottom. In cruisers of great power and high speed the loss of speed would be most serious.

Wood and copper sheathing necessarily involve a very large addition to first cost, and some addition to the charge for maintenance. On the other hand, the long continued cleanness of the bottom reduces the coal bill very considerably, and diminishes the expenses for docking and cleaning. These latter savings may not, on barely economic grounds, be a compensation for the extra initial outlay. Its ample justification is to be found in the fact that the sheathed vessel is possessed of sea-keeping powers and a capacity for maintaining her speed after long periods afloat, such as are impossible to any unsheathed iron or steel ship.

DISCUSSION.

Sir Nathaniel Barnaby, K.C.B. (Vice-President): The paper to which we have just listened is a paper which I think our French colleagues will say is for them, as well as for us, full of interest. It is hardly possible to exaggerate the value of such a paper as this, coming as it does with the high authority of Sir William White; and it is proper, I think, that I should have risen at once to say this, because I am myself in the position of the person criticised by a great deal of the paper. It was my misfortune, during the period from 1870 to 1885, to have to care for the results of sheathing in the ships which we were then introducing, and it is impossible to speak more strongly, I think, than Sir William White has himself done, as to the cost and trouble involved in the double sheathing of wood which we felt obliged to put under the copper. I was myself responsible for some of the ships which are named here, for the *Imperieuse*, the *Warspite*, and the *Calliope*, and for a great number of others, which were sheathed in the manner which has been described. The sheathing of copper was so costly that we turned in despair to a sheathing of zinc, and you have heard from Sir William White that the sheathing of zinc, while it has been continued in the ships in which it was put, is not a successful sheathing. In 1887, when I learned that Sir William White was about to make this great change, and to do away with the inner sheathing of wood which was so troublesome and so costly, I must confess I was not only exceedingly doubtful as to what result would be obtained, but I expressed my doubts to Sir William White himself as to his success. His boldness has been fully justified, and I am glad to be the first in speaking here to give to him the credit that is due to his initiative, and to his great boldness. There can be no doubt about the success of that which he has done. I have noticed one or two points brought up here, one at the bottom of page 33, concerning the advantage of screwing the bolt-end into the plating, of which Sir William White speaks highly, a plan which has been retained, and a plan which is due to my friend and colleague Mr. Barnes. I am glad to find it has the confirmation of the authority of Sir William White, as being a very important detail. We have been told here that the brass used in the bolts is naval brass. The composition of naval brass is not described here—probably our French colleagues know as well as ourselves, but if they do not, Sir William White will no doubt say exactly what it is. It is important that ordinary "yellow metal" should not be used. It is desirable that there should be such a composition as that which we are told has been employed for these bolts. I can only say I feel I represent my colleagues, both English and French, in saying that we have received this paper with the very greatest satisfaction, and are much indebted to the writer of it.

Mr. B. Martell (Vice-President): My Lord Brassey, Ladies, and Gentlemen, I feel very great pleasure in stating that according to my experience the anticipations of Sir William White have been fully realised in the Mercantile Marine, as well as in the Government ships. Some years ago there were several very large sailing ships built on the composite principle. Those vessels were built with two thicknesses of planking, the inner thickness fastened with galvanised iron bolts, and the outer thickness fastened to the inner with copper, that is yellow metal bolts. After some years it was found in cutting graving pieces out, and subsequently taking a plank out of the outside planking for reclassification, that the whole of the plating inside—that is, the broad bilge plate that is fitted to a composite vessel, and likewise the diagonal plates fitted on the outside of the frame to give longitudinal strength—owing to the water finding its way under the planking, was to a great extent eaten away. That caused the principle of the two thicknesses of planking in composite vessels to be given up. I do not think any more were built after that. As you know, a great many composite vessels were

built with a single thickness of planking; and I may say in reply to Sir William White, who alluded to this, that at the present time I do not think there is one ship building in the whole of Great Britain on this principle. The reason is, in fact, that as compared with building of steel ships the expense is so great that they cannot be built in competition with steel. Very recently—within the last five years—a vessel was built, I think called the *St. George*, plated over with $\frac{3}{8}$-in. plating, and she was sheathed with teak 5 in. thick, and fastened with yellow metal screw bolts, the same as mentioned by Sir William White; and I may say that up to the present time experience, I believe, has shown that she has turned out perfectly satisfactory. She was a steamer. I don't think I need say anything more than that; of course, such experience as this corroborates the experience gained up to the present time in the Admiralty with regard to one thickness of sheathing on the outside and bottom of steel ships.

Captain M. Kasy (Member): Having had for a long time to do with war vessels built for foreign stations, I may say that those interested in building iron ships which are intended to be sheathed with copper are certainly, and ought to be, very thankful to Sir William White for the paper which we have listened to to-day. It gives the history of the thing, and more than that, it gives the proof that we can now sheath with wood and copper the bottoms of iron ships with much more advantage and less risk than we did for such a long period of time. In Russia we have always adhered to the system that was first adopted in the earliest period of sheathing iron vessels with wood, in 1866, having had the same experience, as elsewhere, that zinc and yellow metal sheathing did not serve the purpose, for reasons described by Sir W. White. We therefore adhered always to copper sheathing. Having had also some experience with the building of composite ships, we found that yellow metal bolts had to be replaced with bolts of navy metal, and with these we have never had any trouble. Up till now we have been fitting on the outside of iron skins girders of Z form, driving between them vertically wooden chocks on a bedding as described here, well wedged in, the outer layer of horizontal planking being simply screwed to these chocks. We always thought that, combining all other advantages, this system was superior to any other kind of sheathing of the outer skin, because we did not perforate or make a single hole in the ship's bottom, and whatever happened to the outer skin never had any effect at all on the inner part of the hull proper. But the advantages which are connected with the system as now applied since 1887 by Sir William White—that is to say, one layer of thick planking—I think are so great, that even in Russia we ought to give up the excellent system that we have adhered to, and with complete success, for such a long time; Russia being more interested than any other country in this matter, because we have so few facilities for docking our ships abroad. Our special thanks are due to Sir William White for his very useful and very interesting paper.

Mr. C. Artsayooloff (Member): I should like to state my experience in the Black Sea with regard to the sheathing of the circular ship *Admiral Popoff*. Some years ago she was lifted for the purpose of surveying her, and the sheathing, as far as I know, was very good.

Sir William White: How long had she been afloat?

Monsieur Artsayooloff: About ten years.

Rear-Admiral C. C. P. Fitzgerald (Associate): I think this is too technical a subject for any naval officer to discuss in detail; but I want to say that I should like to see all our ships sheathed. Circumstances might arise, and probably will arise, in war time where you could not afford the loss of a knot of speed; it might be vital to the existence of a ship, or even a fleet. Therefore I think, from

a naval point of view, we require all our ships sheathed and coppered, and we do not care a button what it costs.

Sir William White, K.C.B., LL.D., F.R.S. (Vice-President): It would be very interesting if any gentleman present would tell us about the *Vendenesse*, a yacht built in this district, of aluminium alloy, and would state her condition as to freedom from fouling or the reverse. I think I remember reading that there had been some special experience in one of the harbours on the coast with that vessel lying near a copper-sheathed vessel. I know that different systems of submarine paints have been tried on the *Vendenesse*, but I cannot say with what result. She has been painted only—no sheathing has been put on.

My Lord, I have only to thank the various speakers, and the members generally, for the reception that has been given to this paper. It is distinctly, as I have said, a paper of information. I did not intend it to be a paper for criticism. With regard to the system so long and, on the whole, so successfully used in the English Navy—the double thickness of wood—I have been careful to point out that it has done its work thoroughly well, and for fully twenty years it has proved successful in individual ships; and I think if, in the light of wider experience, it is possible somewhat to simplify matters without running into risk, and to reduce weight and cost, it is more to be expected that such a step should be taken after long experience of another system than that the same method should have been adopted at first. One has so much to do that there is a danger always of becoming conservative; and in this matter of sheathing, I should add, especially as one gets older—at which my friend Mr. Martell smiles—if there had not been good reasons for departing from the various earlier systems, they would have been here with us to this day. There were, however, such reasons, and there were examples in the later years of the use of two thicknesses, which were not in agreement with the average results of earlier years. I believe I am committing no indiscretion in saying that in the French Navy, where several ships have been sheathed with two thicknesses of wood, some of them, the *Tourville*, for example (I remember seeing the particulars of it in the Exposition of 1878) —I believe in those ships the general results obtained were very satisfactory with two thicknesses of wood. We have in the English Navy, still on service in the Training Squadron, the *Volage* and the *Active*, launched in 1869, which have given no trouble; but while these results are satisfactory, they are not representative of the later practice, therefore this new departure has been made. I am extremely obliged to Mr. Martell for giving us the result of his special, and altogether exceptional, experience of systems of construction with wood and copper in the Mercantile Marine. I believe he knows more about the history of the subject, and has more experience with regard to it, than any gentleman connected with this Institution, as he has had many opportunities beyond those enjoyed by others. I was very interested to hear from him that somebody had been found to make experiments somewhat on the lines we have followed. To Captain Kasy, and to my friend and former pupil, Mr. Artsayooloff, I express my great acknowledgments for giving to the Institution what we had not before, that is, the general result of now nearly thirty years' experience in the Russian Navy, of the system employed by them. The late Mr. Grantham, in this matter, deserved the greatest credit for his very early and very sensible advocacy of the system which has proved, I understand, on the whole, so very successful in Russian ships, and is there still used. I thank you very much, ladies and gentlemen, for the reception you have given to my paper.

The President (the Right Hon. Lord Brassey, K.C.B.): In offering your thanks to Sir William White, I may allude, in a sentence, to the appeal which Sir William White made to me for the

results obtained in a small vessel with which I am intimately connected. With regard to that vessel I may say that she is twenty-two years old; she is a composite vessel; she has recently been resurveyed by Lloyd's surveyors, and still holds her place in the first class. The boiler is of even date with the vessel, and is still in its place and doing its work with the pressure reduced to 55 lbs. I consider those results extremely satisfactory. I have now only to thank Sir William White in your name, and I am sure, while we all recognise the professional and theoretical value of his paper, we appreciate most particularly the devotion which Sir William White has shown in this particular instance to this Institution, which has always received such valuable support at his hands. In the present case we are more particularly grateful to Sir William White for his paper, because we know that it has been prepared under circumstances of great physical difficulty, which were borne with admirable courage. We have to thank him the more for his paper on that account. Having regard to the conditions under which it was prepared, I am sure I shall have all your hearts when I say that we are glad to see Sir William White so far recovered, and hope that his complete convalescence will be shortly accomplished.

M.G. METER.

By Archibald Denny, Esq., Member of Council.

[Read at the Summer Meetings of the Thirty-sixth Session of the Institution of Naval Architects, June 11, 1895; the Right. Hon. Lord Brassey, K.C.B., President, in the Chair.]

In the year 1887 I read a paper to this Society entitled "The Practical Application of Stability Calculations," in which I described a book called the "Technical Qualities Book." In this book, which is supplied to all seagoing vessels built by my firm, is given a description of an inclining pendulum and diagrams, by means of which the captain can, by a simple experiment, ascertain whether his vessel is seaworthy or not in so far as stability is concerned. These diagrams do not give the actual metacentric height or value of M.G., as we considered at the time that captains might be confused by this information; but give a "safe line," and also other lines, on either side, showing what alterations must be made on the loading to fulfil the conditions assumed. For the exact conditions governing the construction of the diagram I would refer members to my paper of 1887.

Some captains who have taken a great interest in this matter and have practically used the method, have expressed a desire to be furnished with information which would give them the actual metacentric height, and Captain Johnson, of the British India Steam Navigation Company, has constructed an instrument for this purpose.

The diagrams supplied by us since 1887 are, of course, only applicable to the ship to which they were supplied, but Captain Johnson's instrument, he informed me, is applicable to all vessels.

With this idea I schemed out an instrument consisting of a tube bent to the arc of a circle, acting as a species of spirit level, which I understood from Captain Johnson was the method he adopted; but I found that it was practically impossible to get a tube made with sufficient accuracy to allow of this method being successful. Mr. Wimshurst of the Board of Trade has solved this problem in another way, which has already been described to this Society by Mr. Martell, at the Spring Meetings, and I have now to submit another instrument, which I have called the M.G. Meter, and which is the result of the joint work of Mr. William Gray, head of our scientific staff, and myself. From Fig. 2, Plate X., you will observe that this instrument is simply

a spirit level pivoted at one end and adjusted at the other by means of a micrometer screw, combined with a diagram giving the value of M.G.

Along the base of the diagram is an equally divided scale of adjustment of screw, which is simply a measure of the angle of heel. The scale E, which is adjustable in a longitudinal direction, is a scale of equal graduations representing values obtained by multiplying the weight by the distance moved when inclining, and dividing this by the displacement, or, in other words, the value of GG_1, or shift of common centre of gravity. The pivoted bar G gives the M.G. upon the right-hand side and top scale, the lines marked 1, 2, 3, 4, M.G. are simply indicators for convenience in reading of the scale.

To a scientific society such as this, the method of using this instrument from the description I have given will be at once apparent; but it may be of interest if I extract from the "Technical Qualities Book" the instructions we give to captains as to mode of using this instrument, and I should be glad if the members would criticise these instructions, if they do not think them sufficiently clear to be put in the hands of men who have not always had the advantage of a thorough scientific training.

The following are extracts from the instructions:—

"The object we have in supplying the M G. Meter is to enable the captain to test for himself the stability of the ship. This he can do at any time when the ship is in dock or at anchor, provided he has suitable weights to move, the ship is free to incline without coming into contact with wharf or other obstacle, and there is no bilge water or other weight which will shift as the ship inclines.

"The principle involved in the use of the M.G. Meter is that a certain weight moved a certain distance will heel a ship more or less according to her stability; the weights moved across the deck give the means of causing the heel, and the M.G. Meter the means of measuring the amount of heel. One movement of the weights would be sufficient but for uncertainties which always exist. As explained later, we recommend at least two movements, with observations of the M.G. Meter made before the first movement and after each.

"To perform the experiment men sufficient to move the weights are required, perhaps twelve; but the number will vary according to the weight used. An observer is also required for the M.G. Meter. Half an hour ought to be sufficient for an experiment.

"As preparation for an experiment all loose water should be pumped out; all water ballast tanks intended to be full should be pressed up; all movable weights should be secured; moorings likely to cause heel removed; and all fastenings slacked as much as possible. All persons, both passengers and crew, not required for conducting the experiment should remain still during the experiment. Before the experiment all operations in the engine-room, especially all pumping, should be stopped.

"Any portable weight, such as cargo, or even men, may be used. The amount of weight to be shifted is left to the discretion of the captain. Fig. 1, Plate X., gives a general idea of the manner in which the weights used for inclining should be arranged on deck. The important thing is to note carefully the amount of weight shifted after each observation, and the distance through which it is moved.

"Fig. 2, Plate X., gives a sketch of the M.G. Meter, and the following description will explain it. It consists of a spirit level A, which is pivoted at B. The free end of the level may be raised or lowered by

means of the micrometer screw C. The amount of adjustment may be obtained from the scale engraved on the front of the micrometer. This scale gives tenths and twentieths of inches, and, as the screw has twenty threads to the inch, it will advance through one of the small divisions for each turn. The edge of the nut is divided into five, so that the amount of adjustment can be read to one hundredth of an inch. The brass frame D going round the outside of the diagram is grooved inside. In that groove the scale E can move from side to side of the diagram. A slot in this scale carries a small pin F, which also moves in a slot in the straight-edge G, which is pivoted at K. The scale at the bottom represents the adjustment of the screw; that round the edge the amount of metacentric height. The scale on E gives the shift of centre of gravity of the ship, due to shifting a weight across the deck.

"*To find the M.G. of the Ship.*—The weights to be shifted being in position on the deck, the men required for shifting them should be placed in some position to which they must always return after each movement. The ship should be brought as nearly upright as possible. For this purpose it is near enough to adjust the cargo so that she has no visible list.

"Before the first movement of weight the observer should set the spirit level horizontal. This can be done approximately, in the first instance, by moving the instrument round the screws L L, the finer adjustment being made by means of the micrometer, the reading of which will be about 1·0 when the ship is approximately upright. When this has been done, the observer should take a reading of the gauge on the micrometer.

"The weights on the one side must now be moved to the other, and when the men have returned to their respective places the level should again be adjusted by means of the micrometer screw. The difference between the present reading on the gauge and the original will give the amount of adjustment the level requires, to allow for the movement of weight.

"The position of the weights will now be that indicated by B in Fig. 1. One movement of weight would be sufficient, but as a check on the accuracy of the observations we recommend the captain to make at least two. In that case the weights should be brought back to the position shown in C, Fig. 1. If the results of the two observations are approximately the same it will be near enough to take the mean, but if the difference is large the observations will require to be checked by making another movement of the weights, as shown in D, Plate I.

"The amount of adjustment of screw should be set off on the horizontal scale at the bottom of the diagram attached to the M.G. Meter, and the scale E shifted along to that point.

"The distance through which the weights have been moved must be measured, and the draughts of the ship carefully read. From the displacement scale the displacement at that draught may be easily obtained. The weight (in tons) shifted, multiplied by the distance (in feet) that it is moved, and divided by the displacement (in tons), gives the shift of the centre of gravity of the ship. This amount should be set off on the vertical scale E. The straight-edge G should be set to this point on the scale E, and position of G on the scale round the edge will give the metacentric height. The minimum amount of metacentric height that we deem sufficient for a sea-going vessel is eight-tenths of a foot. If she has less than this we consider her too tender. The maximum amount of M.G. admissible for safety and comfort is dependent on so many causes, stowage of cargo, &c., that this will be best determined by the frequent use of the M.G. Meter and observation of the vessel's behaviour at sea."

Having found the M.G. for his vessel the captain might either wish to decrease or increase this, according to his experience; we therefore add a small table* with the following remarks:—

* The figures given in this table are only applicable to a particular ship.

"The M.G. can easily be modified by adding or removing cargo or water ballast. In either case the amount to be put in or taken out can be approximately found by using the figures given in the accompanying table:—

"EFFECT OF 100 TONS OF WATER BALLAST IN THE TANKS, OR CARGO IN UPPER 'TWEEN DECKS, ON THE METACENTRIC HEIGHT OF THE STEAMER AT SEVERAL DRAUGHTS.

Draught.	Water Ballast.	Cargo in U.T.D.
10 feet	·33 feet	·71 feet
13 ,,	·33 ,,	50 ,,
16 ,,	·33 ,,	·30 ,,
19 ,,	·33 ,,	·18 ,,
22 ,,	·33 ,,	·05 ,,

"These figures are intended to be used when the boilers are full as when ready for sea."

It is now nearly nine years since we supplied the first inclining pendulum and diagrams, and, as we anticipated, they have not been so frequently used as we should have liked. We are, however, in no way discouraged by this, and shall continue to supply this instrument in the full belief that ultimately it will become the rule and not the exception for this apparatus to be used.

In one of the latest steamers built by us the inclining pendulum and diagrams were used with the very best result, and I think it will be of interest to the Society if I give a detail of the circumstances under which they were used.

A new cargo vessel built by us was loading at a foreign port for home. After completing loading, the captain inclined her, and found her too tender. He discharged about 200 tons of cargo and coal—the cargo from the poop, and the coal from the upper bunker. He could not correct the stability by adding water ballast, as she was down to her marks. Her M.G. when inclined was ·46 of a foot, and after discharging was ·7 of a foot. On another voyage the captain again inclined this vessel at an intermediate port with the bunkers practically empty, when the M.G. was found to be ·67 of a foot, so that from this vessel our limit of ·8 of a foot seems to be reasonable. I think the information of great practical and scientific value.

The instrument before you is the second we have made, and is, no doubt, open to improvement. The first was supplied to the S.S. *Semiramis*, built by my firm for the Austrian Lloyd's Steam Navigation Company. We have practically tested this instrument in comparison with the pendulum, and we find that it is extremely accurate, and is a much more convenient instrument to use. In future it will always be used in finding the centre of gravity of our vessels before leaving the yard.

The President (the Right Hon. Lord Brassey, K.C.B.): In your name, gentlemen, I desire to offer to Mr. Denny our sincere thanks for his most useful paper. It is quite clear if shipowners will place in the hands of their captains some instrument by the use of which the risk of capsizing—a disaster which has sometimes occurred—could be avoided, it would be of great service. I think Mr. Denny is doing what is most useful in pressing this suggestion, through the Institution, on the consideration of shipowners.

PRELIMINARY PROCEEDINGS.

WEDNESDAY, JUNE 12, 1895.

Before commencing the reading of papers Monsieur Bertin showed some projections on the screen of a series of instantaneous photographs of various objects in motion, including a series, taken at sea, which analysed a simple movement of pitching and rolling of the French warships, the *Marceau* and *Tourmente*.

Afterwards Monsieur Lippman projected on the screen several examples of his interesting discovery of the art of photographing in natural colours.

The President (the Right Hon. Lord Brassey, K.C.B.): On behalf of the Institution of Naval Architects, I desire to offer to Monsieur Bertin and Monsieur Lippman our sincere thanks for the very interesting exhibition which they have given us. I am sure we are all very much obliged to them. I now call on Mr. Holmes to read a paper prepared by Monsieur Daymard.

ON THE UTILITY OF CALCULATING THE WHOLE EXTERNAL VOLUME OF SHIPS, AND CONSTRUCTING THE COMPLETE SCALE OF SOLIDITY FROM THE POINTS OF VIEW OF "STABILITY," "TONNAGE," AND "LOAD-LINE."

By Monsieur V. Daymard, Member.

[Read at the Summer Meetings of the Thirty-sixth Session of the Institution of Naval Architects, June 12, 1895; the Right Hon. Lord Brassey, K.C.B., President, in the Chair.]

The calculations relating to the total amount of closed spaces of a ship and the construction of a complete scale of solidity are already employed by several naval architects and shipbuilders.

I take the liberty of recommending this practice, which may be useful either in the present or in the future, from the triple point of view of "stability," "tonnage," and "load-line."

I shall refer only to a few considerations on each of these three features.

I.—Stability.

The disasters which have occurred in our time to merchant ships as well as men-of-war, which have capsized in a most unexpected and deplorable manner, and have been lost with all, or nearly all, on board, show that, notwithstanding the progress of modern science, the complication of actual ships is so great that it is more necessary now than ever to investigate thoroughly the stability in all cases, and particularly at large angles of inclination.

The forces tending either to right or to upset the vessel must be calculated, in all positions, and [as humorously expressed by one of our Vice-Presidents] the naval architect must completely capsize his ship on paper in order to assure himself that the like will never happen at sea.

This necessitates the finding of the total volume and the position of the "centre of bulk," an important point in tracing the general curves of stability described and

determined under the name of "Pantocarènes Isoclines" * in a paper I had the honour of submitting to the Institution of Naval Architects in 1884.

In the case of an ironclad, with a protected deck and superstructures upon it, two vessels have to be considered: one formed by the protected part only, which may be all that is preserved after an action; the other, including all the superstructures and closed in spaces, in order that the stability, rolling, and nautical qualities of the undamaged ship may also be investigated.

II.—Legal Tonnage.

Notwithstanding the almost general adoption by maritime States of Moorsom's method for the internal measurement of ships, we sometimes arrive at widely different results in ascertaining the legal tonnage of ships.

After the warm discussion on the subject of Suez Canal rates at the International Committee, assembled at Constantinople in 1873, it may be admitted by impartial men that none of the maritime States possessed a quite satisfactory system for the determination of net tonnage. Moreover, it was necessary for the payment of the Suez Canal rates to adopt a special tonnage, which, although more rational than most of those used elsewhere, is still objectionable. The great divergences in the value of tonnage, not only in passing from one nation to another, but even within the same country, are extremely injurious and prejudicial to commercial affairs.

These differences occur principally from the way in which deductions are made, and result also from the difficulty of fixing exactly the internal capacities, which must be included in Moorsom's measurement—for example, the water-ballast spaces.

It is not an exaggeration to say that with regard to tonnage, and especially referring to the different maritime States, a real "anarchy" prevails, which claims for pressing reform and international agreement.

Now, I think it would be possible to solve the problem by considering the whole external volume of ships.

In order not to alarm those who have to pay tonnage dues, it is necessary to say at the outset that the *conditio sine quâ non* of reform and unification of tonnage must be that the shipowners have, under no circumstances, to pay heavier dues than at present.

While desirous of introducing simplicity and uniformity, I do not forget that the first necessity is to tax at minimum rates the ships which are, above all, the instruments of commerce and civilisation.

* The above name may have looked perhaps rather barbarous, but it was, in my opinion, justified by the use generally admitted of the word "Isocarène," originated by Charles Dupin.

That being understood, I would propose the following general manner of establishing the tonnage.

The point of departure would be the total external volume without any deduction, but the "divisor" would be increased; instead of 2·83 for cubic "metres," or 100 for cubic feet, I should use, for example, divisors of double value.

In this way a figure would be arrived at proportional to the bulk of the ship, in relation to which it is reasonable to fix the dues paid on the gross tonnage.

The taxes on the net tonnage which must correspond to the importance of commercial operations, would be computed in exact proportion to the tonnage of goods loaded or discharged.

This is not an entirely new practice, and prevails already in several ports, notably in Spain.

The total effect, it may be repeated, would be to ensure that, after all, in average terms, shipowners would not have to pay increased rates, but even less, if it be possible without injuring the interest of States, corporations, or private bodies, which have to bear the expenses of lighthouses, ports, quays, &c.

At all events the basis of dues would be more equitable and rational than it is now, and we would no longer witness such shocking anomalies as a tug boat with a negative tonnage, or a vessel, nominally of 70 tons, discharging on the quay not less than 500 tons.

It would, in my opinion, be comparatively easy to solve the difficulties which perhaps might be raised as to the exactness of the "sheer plans" or "body plans" supplied by the shipowners and shipbuilders, for the measurement of volume, and of reproducing drawings which sometimes did not exist at all.

Public Departments, like the Board of Trade in the United Kingdom, or the "Administration de la Douane," in France, which have to ascertain the tonnage of ships, are as competent to defeat any attempt at fraud by means of false plans of ships, as to guard against any erroneous information which might be supplied to them by shipbuilders concerning their engines, boilers, safety valves, and other mechanical appliances.

Measurements less complicated than those actually used for the calculation of gross tonnage will certainly allow of verifications of the body plans supplied, or, in the rare cases of very simple vessels of which no drawings exist, to make up for them with sufficient correctness.

Moreover, I do not think the objection can be raised that, even with the plans in hand, the calculations will present too great difficulty. They only require the most elementary knowledge of arithmetic and geometry, such as is now to be found in the most unimportant shipyard, and would, in fact, be more easy than those now necessary for ascertaining the internal capacity, and for making the corrections regarding the superstructures, the deductions, &c.

III.—Limit of Draught or Load-Line.

Among the data required for fixing the maximum load-line with reference to security at sea, whether this line be fixed by the shipowner himself or by a compulsory Government rule, the most important element for each type of ships, other things being equal, is certainly the "percentage of reserved buoyancy."

Now, a complete scale of external displacement constructed from the calculation of the total volume, and which might be graduated in hundredths, will enable anyone to read off at a glance the "reserved buoyancy" corresponding to a given draught, or the draught corresponding to a required "percentage of reserved buoyancy."

I think that with this system the complication of measurements and calculations as well as the chances of error would be less. The basis would be more mathematical and clearer than with the method (which I have pleasure in acknowledging to be very ingenious) of "co-efficients of fineness,"or the application of rules referring to the load line.

Abstract and Conclusion.

To sum up this paper, my object in recommending—

(*a*) The calculation of the whole external volume of ships,
(*b*) The fixing of the centre of this volume,
(*c*) The construction of the complete scale of solidity,
(*d*) The embodiment of these in the plans and specifications,

was to indicate that these data may be useful for the survey of stability, for a possible general reform and simplification of the rules of tonnage, and also for the fixing of the load-line.

The last point has been previously submitted at meetings of the Institution, but it appeared to me that it would not be without interest to insist upon the others, and to bring to light the bundle of reasons which shows the utility, possibly to be found, in the habitual use of the calculations and data in question.

DISCUSSION.

Mr. B. Martell (Vice-President) :—My Lord, Ladies and Gentlemen, in the first place, I must say we are greatly indebted to Monsieur Daymard for grappling with this very difficult question. If he can only solve the question of determining what is the proper rule for ascertaining the tonnage on which dues are to be paid, I am sure he will have done a very great act indeed, and deserve the eternal gratitude of dock companies, &c., and shipowners generally. But I must say it is an exceedingly difficult subject. We have had committees formed in England who have had before them experts and gentlemen of great experience, who had to enter into explanations of their views and answer questions of the committee in order to enable them, if possible, to recommend to the Board of Trade some rule by which those anomalies, referred to by Monsieur Daymard, might be overcome. But having sat for some considerable time—weeks or months—they ultimately have come to the conclusion that you had better let sleeping dogs lie, than make an alteration which they could not see how to make without involving just as many anomalies as they swept away. The tonnage question is a very difficult question indeed. I cannot conceive anything better than Moorsom's rule for ascertaining the internal capacity of ships, the number of cubic feet inside the ship, according to her form. The reason why the divisor of 100 referred to by Monsieur Daymard was adopted in that case was that, it would be highly injurious to commerce, and to the country itself, if you made a great alteration in the amount of its tonnage. Great Britain stood always at the top of the list in regard to the greatest amount of tonnage possessed by any nation in the world, and she naturally wanted to retain that position. She did not want a rule by which tonnage could be reduced by about half, and the consequence was that, a divisor had to be ascertained by which the amount of tonnage could, as nearly as possible, be retained, and it was rather a peculiar coincidence that, having obtained the cubical capacity of the ship by dividing it by 100, you as nearly as possible came to the same tonnage as you had by the old builder's rule of calculating tonnage. Calculating in that way involved no alteration in the tonnage registered in the British Register. Of course the great anomaly is that referred to by Monsieur Daymard, of a ship having *negative* tonnage. It is a scandal to any nation that such a thing should exist, and that means could not be found to endeavour to prevent it, but fortunately this has been done. One great difficulty exists with regard to the rule allowed for steamers. It was felt, to encourage steamers in the early times, that it was necessary for paying dues, that you should not calculate the whole capacity of the ship as you would in a sailing ship, seeing that a large portion was taken up for propelling purposes, and was not earning any money by carrying cargo; and that, again, by framing a rule by which a greater allowance could be otherwise made by increasing the engine-room, you added very considerably indeed to the comfort of those engaged in the engine and boiler-room, and that law was brought into operation in order to carry that out. Whether it is a right proportion, or not, is another thing, and we found, having thoroughly considered the thing, that no effective rule could be made for the alteration of that. Now, with regard to the freeboard question, I may say that in framing those tables which are now adopted, very nearly on the lines that I and my staff got out originally, and the co-efficients that were necessary to determine the amount of reserve buoyancy in every form of vessel, we did practically what Monsieur Daymard refers to, and mentions here. We obtained the drawings of hundreds of ships, and calculated the actual displacement up to the gunwale of all those ships. Having done that, and ascertained what the co-efficient of fineness should be, so as to be enabled to cut off the exact proportion of percentage of reserve buoyancy in every vessel according to its form, one of my assistants went round to various ports and invited the shipbuilders to supply him with drawings of their ships, which they had calculated themselves, and by applying this co-efficient of fineness to see what the difference would be by adopting that co-efficient. One of the members of the

committee (Mr. Robert Duncan) rendered us the greatest assistance in that respect, as well as the late Mr. William Denny, who was one of the most intelligent members of our committee, and he entered most enthusiastically into the subject. Having had all this information placed before them, they came to a unanimous resolution that no ill effects could result from adopting this co-efficient of fineness, and that very simple and easy manner of cutting off the amount of reserve buoyancy considered necessary, was as correct for all practical purposes as if you placed the vessel in dry dock and took the measurement of it, and calculated the reserve buoyancy by that. There is no doubt that by the method proposed by Monsieur Daymard, it would apply only to vessels having full scantlings up to the gunwale. When you go beyond that you must modify the rule as we do with our freeboard tables, for the value given to erections on the deck is not of the same amount in character as that given to the main part of the hull, and consequently you are obliged to modify that according to the type of ship, the erections raised, the value of them according to the effect produced, and various other considerations too numerous to mention. Shipowners once said, "It never can be done; let us remain as we are, and let us fix our own load-lines." Eventually they found it could be done; it has been done, and has given satisfaction to shipowners and those interested generally. I can only express our great thanks to Monsieur Daymard; and these few criticisms which I have felt bound to make on his very valuable suggestions, I am sure he will take in the kindly spirit in which they are offered.

Mr. Archibald Denny (Member of Council): My Lord, the question of altering the tonnage laws is, as Mr. Martell truly says, one of extreme difficulty. Mr. Martell had peculiarly good opportunities for studying that question—if he were not himself a member of one of the Tonnage Committees some of his assistants were—and he, no doubt, found what we all know to be the case, that it is a purely commercial question, and it is exactly because there are anomalies that it is not possible to do as Monsieur Daymard thinks, and produce a rule which will have such an application that every man will pay exactly what he pays now. It cannot be done. You may say no person is to pay more, but some will be called on to pay less, and one shipowner will not be at all pleased if by the new law he finds his neighbour is getting an advantage over himself, or thinks he is. I think I may say it is not now true that there are such tonnages as negative tonnages. They no longer exist. They arose in a very simple way from a flaw in the tonnage laws. It was possible to deduct from the tonnage what you had not added to it. That seems an anomalous thing, but it was so. You might deduct air casing, skylights, and what was above the engines from the gross which you had never added to it. Now the law is altered, and for whatever you now claim deduction you must in the first place add. As to the question of machinery deductions, these are, I think, quite absurd. No person can defend them for a moment. But they are there, and they have their effect upon rates just now, and it is jealousy and the delicacy of the situation which prevents it being altered. I am afraid the rules will have to be continued for a little longer time, till human nature changes for the better. As to freeboard tables, none of us can deny that Mr. Martell, in the first instance, and the Load Line Committee in the second, deserve the greatest credit for producing tables which, in an approximate manner, give something like a reasonable freeboard. When I say they give a reasonable freeboard, I must qualify that, because I think in some instances they do not do so, more especially at the upper end. I think Mr. Martell will agree with me that that is so. I think there is no doubt that for larger ships the freeboard is too great, and that, sooner or later, there will require to be either a conference of bodies interested, or another Load Line Committee to slightly modify this. Reserve buoyancy was not the only thing considered in freeboard. There was also the question of height of platform. I think perhaps if another committee sat they might discover, from the larger and more accurate experience that we have at present, from

the enormous number of ships now dealt with as to freeboard, that certain small points might with great advantage be modified. Looking at the general question of taking the whole volume of the ship into consideration, I think I may say that many shipbuilders do that already. As to stability, it is the practice of many of our best shipbuilders to make cross curves of stability for very many draughts. Having got this, they naturally get the total volume of the ship and the centre of buoyancy at different inclinations and the general stability of the ship. Of course we never can be too often reminded of what is necessary to be done, and I personally thank Monsieur Daymard for bringing this before our notice. I feel Monsieur Daymard's suggestion as to dues being paid upon cargo actually loaded a peculiarly valuable one, and worthy of most serious consideration by all interested.

The President (the Right Hon. Lord Brassey, K.C.B.) : I wish to join those who have already spoken in expressing our grateful thanks to Monsieur Daymard for his paper. It is evident that the subject which he has been treating is of the highest interest. It is quite evident that a uniformity of rule for the measurement of tonnage is much to be desired, but speaking of this subject from a shipowner's point of view (and I daresay there are a good many shipowners here—a good many gentlemen who have got shares in ships), I am perfectly convinced that, there is no advantage to them to be gained by any reduction in the fixed burdens which they have to carry in the form of these, because this is perfectly certain, that the unrelenting competition which prevails in the trade will give the full benefit, and that immediately, of any reduction of charge to the public.

Monsieur V. Daymard (Member) : I know well the extreme difficulty noticed by Mr. Martell in modifying the rules of tonnage. I agree with Lord Brassey that the abatement of dues, obtained by the application of the actual rules, in reality benefits the public. Notwithstanding, I persist in thinking that something is to be done towards an equitable redistribution of those advantages among the shipping community. A corporation like our Institution has not to propose the details of new legislation, but members can be allowed to point out the principles in accordance with which it is possible to improve the existing legislation. I am confident that, in time, the whole external volume will be employed instead of the gross tonnage, and the amount of cargo loaded or discharged instead of the net tonnage. Referring to the load line, and the use of exact volume in place of the co-efficient of fineness, for the calculation of the reserve buoyancy, I am very well aware of the considerable work accomplished in Great Britain on that question. I have had in hand, and have gone through the voluminous books containing inquiries and reports of the Load Line Committee, and I fully recognise the immense praise deserved by the Committee for arriving at practical conclusions. I am quite satisfied to learn from Mr. Martell that more and more numerous verifications show that, the co-efficient of fineness conduces to almost identical results with those obtained by the exact calculation of external volume. However, I think that, with increasing variety of types, the last method has a good chance of being used in the future. Answering Mr. Denny, I acknowledge—as I stated in my paper—that several shipbuilders, and the firm of Messrs. Denny among the most important, already make very complete calculations concerning the stability even of commercial ships. I wish merely for the generalisation of such practice. Before sitting down I wish to express a regret. At the beginning of my paper I alluded to one of the Vice-Presidents of the Institution, who intended to be present at the meeting. I refer to Sir Edward Reed, who is prevented by an indisposition, which I hope is not serious, from being present in Paris. This absence of one of the founders of the Institution of Naval Architects will be regretted, not only by his countrymen, but also by all members present who are familiar with the works of Sir Edward Reed, and are indebted to him more especially for his book, published thirty years ago, on iron and steel ships. I beg to thank Lord Brassey, Mr. Martell, Mr. Denny, and the meeting for the interest taken in my communication.

ON STEAM VESSELS OF LIGHT SCANTLINGS FOR SPECIAL PURPOSES OF TRADE.

By B. Martell, Esq., Chief Surveyor of Lloyd's Registry of Shipping; Vice-President.

Read at the Summer Meeting of the Thirty-sixth Session of the Institution of Naval Architects, June 12, 1895; the Right Hon. Lord Brassey, K.C.B., President, in the Chair.]

At the recent Spring Meeting of this Institution a paper was read by Mr. Rickard on "Light Draught River Steamers," in which he remarked:—"It is possible that the registration societies may at some time turn their attention to the construction and classification of very light scantled vessels for river purposes, &c., so as to enable Underwriters, and others interested, to form a comparative valuation of such structures for insurance, or other purposes."

I was considerably surprised at these remarks, coming as they did from a person so well acquainted with the action of Lloyd's Register Committee as Mr. Rickard is; and in the few remarks that I made on the paper I stated that hundreds of vessels of these types had been classed, and could be seen in Lloyd's Register Book. Feeling that an impression might largely exist that no provision was made for including such vessels in the Register Book, I thought the subject of sufficient interest to prepare a paper dealing with the various descriptions of light scantling vessels which had come under my official notice, and which had been surveyed by the Surveyors to the Society, and classed in the Register Book with which I am associated.

In dealing with such a subject, and indicating the scantlings which would be found sufficient for many steamers requiring to draw comparatively very little water, and the scantlings of which would, therefore, have to be considerably less than would be required for similar-sized vessels intended for general purposes of trade, I have thought it desirable to describe only those which have been found by experience to be sufficiently strong to perform their work efficiently in the various trades for which they were specially constructed.

The description of light scantling vessels constructed for various purposes of trade and classed in Lloyd's Register may be divided as follows:—

Steamers for river purposes.
Steamers for river and inland waters.
Steamers for river and short coasting purposes
Steamers for long coasting voyages.
Steamers for Channel purposes.
Steamers for Continental and special excursion service.
Paddle steamers for shallow river purposes.
Stern-wheel steamers for shallow river purposes.
Steamers for cargo-carrying on rivers, such as the Rhine, &c.
Steamers for dredging purposes.
Steamers for ferry purposes.

Many vessels of the above description are designed for carrying a limited amount of cargo in addition to passengers, which renders it somewhat difficult to describe them, but the following general description will probably suffice :—

Plate XI.

Fig. 1 and Fig. 1a.—Iron paddle vessel intended for passenger service on rivers and inland waters. The deck shown by ticked lines represents a bridge the length of the paddle-box, and used for navigation purposes, the steering gear being fitted thereon.

Fig. 2 and Fig. 2a.—Steel paddle vessel intended for passenger service on rivers and inland waters. This vessel is fitted with a long deck-house or saloon, extending from fore end of boiler space to near the stern. The deck over the saloon is used as a promenade with sitting accommodation.

Plate XII.

Fig. 1 and Fig. 1a.—Steel paddle vessel intended for passenger service on rivers and inland waters. This vessel is fitted with a long deck-house or saloon, extending over about two-thirds the length of vessel. The deck over the saloon is used as a promenade with sitting accommodation.

Fig. 2 and Fig. 2a.—Steel paddle vessel intended for passenger service on rivers and inland waters. This vessel is constructed with a promenade deck all fore and aft, and above same a light shade deck is fitted extending for about 250 ft. from the stern.

Plate XIII.

Fig. 1 and Fig. 1a.—Steel twin-screw steamer intended for river purposes only. Such vessel can carry about 190 tons of cargo on a load draught of 7 ft., and, in addition, is fitted for passengers. A promenade deck is fitted all fore and aft, with a light shade deck above same, affording shelter from the sun. The form of the vessel

at the gunwale, as shown on the section, is adopted to give additional deck room, besides which it serves as a protection to the vessel's side and bilge while berthing at sloping wharves and quay walls.

Fig. 2 and Fig. 2A.—A similar vessel to that above described, but of larger dimensions, and carrying about 205 tons of cargo on a load draught of 6 ft. 6 in.

Plate XIV.

Fig. 1 and Fig. 1A.—Steel twin-screw steamer intended principally for cargo carrying on rivers and short coasting service, but also provided with accommodation for a limited number of passengers in a deck-house. Such vessel can carry about 134 tons deadweight on a load draught of 6 ft.

Fig. 2 and Fig. 2A.—Steel screw steamer similar to that above described, but of larger dimensions, and carrying about 465 tons deadweight on a load draught of 8 ft. 8 in.

Plate XV.

Fig. 1 and Fig. 1A.—Steel twin-screw steamer intended for long coasting service, about 1,500 miles, carrying fruit and light goods on a limited draught of water. Also fitted for passenger accommodation, with deck-houses and light shade deck for a portion of vessel's length. Such vessel can carry about 520 tons deadweight on a load draught of 9 ft.

Fig. 2 and Fig. 2A.—Steel screw steamer, intended for long coasting service, about 4,000 miles, carrying cargo and fruit in the holds and 'tween decks, and having large passenger accommodation. A continuous shade or promenade deck is fitted above the main deck, and above the promenade deck is an upper shade deck serving as a protection from the sun, while above the upper shade deck a large dining-saloon and hall are fitted.

Plate XVI.

Fig. 1 and Fig. 1A.—Steel paddle vessel intended for Channel service, carrying passengers and mails, and a limited quantity of light produce. A long deck-house and a long forecastle are fitted.

Fig. 2 and Fig. 2A.—Similar vessel to that above described, but of larger dimensions. This vessel is fiettd with a continuous shade or promenade deck all fore and aft.

Plate XVII.

Fig. 1 and Fig. 1a.—Steel paddle vessel intended for Channel service, carrying passengers and mails, and a limited quantity of light produce. Gangway doors are fitted in the sides of the 'tween decks.

Fig. 2 and Fig. 2a.—Similar vessel to that above described, but of larger dimensions.

Plate XVIII.

Fig. 1 and Fig. 1a.—Steel paddle vessel intended for Continental passenger and special excursion service. This vessel is constructed with an awning deck all fore and aft, on which are deck-houses or saloons, and a promenade deck for passengers' accommodation is fitted above the deck-houses, extending from the fore-mast to within a few feet of the stern.

Plate XIX.

Fig. 1 and Fig. 1a.—Steel paddle vessel intended for passenger and cargo service on shallow rivers, carrying about 190 tons on 4 ft. 9 in. load draught, or, without cargo, having a draught of only 2 ft. 6 in. This vessel is fitted with a light shade deck all fore and aft, serving as a protection from the sun.

Fig. 2 and Fig. 2a.—Similar vessel to that above described, but of larger dimensions, carrying about 800 tons on 6 ft. load draught, or, without cargo, having a draught of only 3 ft.

Plate XX.

Fig. 1 and Fig. 1a.—Steel stern-wheel vessel, intended for service carrying passengers, or exploring on shallow rivers. The vessel is fitted with a light shade deck extending from the stern to within a short distance from the stem, and having a deck-house above same. She is also armed with machine guns. This vessel is made in sections, so as to be easily transported to the locality for which it is intended, and can be put together, and steam raised ready for service, in less than seven hours.

Fig. 2 and Fig. 2a.—Similar vessel to that above described, but of somewhat larger dimensions. She is built in the usual way, and transported complete, instead of in sections, as adopted in the vessel shown in Fig. 1.

More than a hundred of such vessels have been designed and constructed by Mr. A. F. Yarrow, of Poplar, and many of them are nearly twenty years old, and are still

doing their work in a satisfactory manner. This is an evidence of the enduring qualities of vessels with very slight scantlings, where they have been originally efficiently built, and care has been taken to keep the surfaces of all parts clean, and protected by careful painting.

Plate XXI.

Fig. 1 and Fig. 1a.—Iron twin-screw steam barge intended for cargo carrying on the Rhine and similar rivers. This vessel is of great length in proportion to the depth, and is constructed with large hatchways.

Fig. 2 and Fig 2a.—Steel twin-screw steam barge, similar to that above described, but of different dimensions.

Plate XXII.

Fig. 1 and Fig. 1a.—Steel twin-screw hopper dredger intended for dredging work, and arranged so as to load the products of the dredging operations into a hopper on each side of the well. When these are filled she proceeds to sea to discharge the contents. Such a vessel can dredge to a depth of about 40 ft., and is constructed to carry a total weight of from 700 to 800 tons in the hoppers.

Plate XXIII.

Fig. 1 and Fig. 1a.—Steel double twin-screw vessel intended for ferry purposes, carrying vehicles and passengers. The wood deck is covered with blocks of wood fitted with the grain vertical in the same way as wood paving in roads is fitted, in order to provide for the wear due to the heavy traffic of horses and vehicles. Strong wood fenders are fitted to protect the vessel's sides in going alongside the landing-stages, and strong hinged gangways are fitted at the sides of the vessel as indicated on the section.

Fig. 2 and Fig. 2a.—Iron and steel paddle vessel intended for ferry purposes. This vessel has iron framing and steel plating, and is constructed with a strong bridge deck over the midship portion of the vessel for the carriage of horses and vehicles, and the bridge deck is sheathed with American elm to provide for the heavy traffic. The arrangement of a superstructure as indicated reduces the inclination of the floating landing-stage during low tides. Passengers are carried on the main deck.

From the above it will be observed that the Committee of Lloyd's Register are prepared to undertake the survey and classification of vessels intended for every purpose of trade, whether the scantlings are in accordance, or not, with the rules framed

for vessels engaged in general trade, provided drawings be submitted setting forth the intended scantlings, and these are found, in the opinion of the Committee, to be suitable for the special trade in which the vessels are to be engaged.

In conclusion, it may be said that this paper is a complement to that referred to, contributed by Mr. Rickard to the Transactions of this Institution, as, although indicating the types of vessels required, specially for river purposes, to meet certain exigencies, he does not indicate in his paper the minimum scantlings which experience has shown can be adopted, and hence the outcome of this paper to supply this deficiency, and to extend the description and size of vessels having lighter scantlings than those framed for vessels engaged in general trade. The subject, before the production of Mr. Rickard's paper, had not been dealt with at the meetings of the Institution of Naval Architects, and it is hoped the information now furnished will be found of sufficient interest to justify occupying the time of members of a great scientific institution, though it is felt the same may be considered by some a matter of comparatively insignificant moment.

I am greatly obliged to many gentlemen for furnishing me with the particulars of many of the vessels included in the illustrations, and to them I beg to tender my best thanks.

DISCUSSION.

F. Elgar, Esq., LL.D., F.R.S.E. (Vice-President): I rise, my Lord, in obedience to your call, though I have but few remarks to offer upon this valuable paper. I must say, however, that the best thanks of the Institution are certainly due to Mr. Martell for the amount of useful information and the practical data he has given us in connection with a large number and variety of very interesting vessels. All who have had to do with the design and construction of steamers for special services, and especially of such as require to be of very light draught of water and high speed, will know how to appreciate the value of the detailed information Mr. Martell has given in such a handy form in this paper. There is one point that might be mentioned, to which I do not think Mr. Martell refers, as it has a very important bearing upon the strength of this class of vessels, and also upon their safety; and that is the number and arrangement of the bulkheads. In vessels of such proportions as we find described in this paper, that are built of light scantlings, large bulkhead division constitutes a very important element of strength. It adds very greatly to the structural strength, and it also adds to the rigidity and stiffness of the hull, so as to contribute very materially to the comfort of passengers. A good number of bulkheads is essential to safety in the event of accident; and is valuable at all times in giving stiffness to the hull and reducing vibration. There has been a great tendency to keep down the number of bulkheads in some of these vessels, although it is surely very important, in view of the service upon which they are often employed, that the bulkhead division should be very thorough and complete, so as to afford as much protection as possible

against foundering in the event of collision. Some of the vessels, such as here described, are employed in carrying a very large number of passengers, and they often ply in crowded rivers, or in narrow waters that are much frequented by shipping, where they are exceptionally liable to collision. There are paddle steamers we know of carrying many hundreds of passengers, which have no bulkhead division that could possibly be effective, in preventing foundering, if one of the compartments of the hull were to be accidentally laid open to the sea. The continued safety of such vessels is due to their fortunate preservation from accidents. I might, perhaps, refer to the vessel illustrated in Plate XVIII. as an example of one which is so subdivided by bulkheads that, in the event of any two compartments being opened up to the sea, she would float with safety. This is a point that demands the most serious consideration of all concerned in the construction and employment of lightly built steamers that carry large numbers of passengers and travel at high speeds in crowded waters. Another point is that, I am sure all must be pleased to hear Mr. Martell's statement that, the Committee of Lloyd's Register Society are prepared to undertake the survey of vessels intended for every purpose of trade, including such as are described in this paper. Some of us may at times have felt we had grievances against Lloyd's Register Society for being unduly hard in dealing with designs of ships of light scantlings—ships that necessarily have to be built of very light scantlings in order to make them suitable for the purposes for which they are required, and for the shallow harbours or rivers in which they have to run. In putting forward our designs or proposals for such vessels our attention is often concentrated upon the difficult question of how to make them light enough to fulfil the conditions that are imposed upon us. We require to remember, however, that Lloyd's Register Society, or any other registration society, accepts grave responsibility when it undertakes the classification of vessels in which strength has been cut down to the finest possible point—especially when they are intended, as many are, to carry an exceptionally large number of passengers. I can only say, with reference to this matter, that I have had to do business with Lloyd's Register Society, chiefly through our friend Mr. Martell, in connection with vessels of very light scantlings, and it has been my experience that Mr. Martell was not difficult nor unreasonable to deal with.

Mr. Archibald Denny (Member of Council): My Lord and Gentlemen, I would like at once to say that I deeply deplore that Lloyd's Registry, or any other Registry, have anything to do with this class of boats. I have always had the feeling that they are a speciality, and, as they involve the greatest amount of study and care on the part of the builders, they should only be built by builders who are capable of giving that study and care to them. I deplore the generalisation of the knowledge which has cost many of our best shipbuilders a long series of years of calculation and expense to arrive at, and its becoming public property. No doubt you will think that that is a mean motive; it may be a mean motive, but we are all obliged to look out for ourselves in business.

The President: It is poor human nature.

Mr. A. Denny: It is human nature again, as I mentioned with regard to tonnage when speaking on M. Daymard's paper. I think you will agree with Mr. Martell when he says that his Registration Society will undertake the classification of these boats, whether the scantlings are in accordance with their rules or not. I happen to know two of the vessels—one of them very intimately—on Plate XII., the vessel 299 ft. long—and I think I recognise the one on Plate XVII. Mr. Martell's description of the service of the vessel on Plate XII. is, perhaps, not quite accurate. That vessel trades in a similar trade to the vessel in Plate XVII., practically; it is a cross-Channel trade, and I think if you will study the two sections you will see there is a vast difference between the scantlings, and yet

they were both classed. The plating in one is virtually $\frac{5}{16}$, and in the other $\frac{7}{16}$. I may say that there is no large difference in the draught and deadweight carrying capacity of these two boats, which, if I am right, are practically identical. My firm have all along taken a great interest in this class of vessel. I know in the case of the vessel in Plate XII. it was classed after it was built. It was a pure question of insurance; the owners thought they could save something on the insurance. Some owners think—wrongly, I believe—they would have a difficulty in insuring their vessels if unclassed. Mr. Martell will agree with me that, one of the principal objects of Registry Societies is to ensure that vessels are reasonably well built, and to satisfy the underwriters that they are so, whoever they are built by; but in the case of these special steamers, built, as they almost invariably are, by builders of the highest reputation, no such guarantee is really needed. I think that timidity of owners is one of the reasons, probably, that a number of these vessels, as to which, otherwise, you can see no object in classification, have been classed. Take, for instance, stern-wheelers; they are a pure speciality, and the name attached to these vessels—that of Yarrow—is quite sufficient guarantee for any underwriter to take the responsibility for them, if he wishes to underwrite them. His firm has a world-wide reputation. Mr. Martell, I am sure, will not misinterpret my sentiments—I do not put them on a very high platform—but I should like you to believe that I am really honest in what I say as to my belief that, no class is needed for these special vessels when built by first-class builders.

Mr. A. F. Yarrow (Member of Council): My Lord and Gentlemen, I should like to add a few words in confirmation of what Professor Elgar has said as to the value of this paper. The literature on shallow-draught steamers is very limited, and therefore the Institution is under a special obligation to Mr. Martell for having given us a paper not filled with numerous fancy drawings, but with a lot of very important data, the value of which every practical engineer will appreciate. I should like for a moment to refer to Plate XX. The upper of the two drawings represents a class of vessel of which we have built several, one of which we had the very great honour of constructing for the French Government, called the *Opale*, for service on the shallow rivers of Dahomey. This vessel was built some three or four years ago. We felt it as a great compliment for the French Government to place the order with us, and as evidence of the exceedingly liberal and free trade feeling which exists on the part of the authorities in Paris, which feeling we all hope may extend as time goes on. I will make one or two remarks in connection with this vessel by way of explanation, as I think it may be perhaps interesting to the meeting. Please refer to the longitudinal sketch (Plate XX.). The point is this: if a vessel of very shallow draught is to be sent abroad, it has either to be riveted together and launched on the spot, which involves a long delay and skilled labour, or it cannot be sent at all, being mostly far too bulky to ship whole and too weak a structure to send to sea. The problem, therefore, is to construct a vessel which can be shipped in pieces, and put together with very great rapidity, thus avoiding the difficulty and delay of riveting up and launching. We make the sections of such a size that they can be shipped whole, being about 18 ft. in length and 10 ft. or 12 ft. wide and 4 ft. to 5 ft. deep. Each section is completely intact by itself with a bulkhead at each end. There is a very strong angle-iron frame uniting the bulkhead with the skin plating, through which the bolts are passed to unite the sections together. If the section of the hull were made simply as described, when it is lowered the water will pass through the bolt holes and the section would sink. To avoid this, a high floor of about 15 in. deep is built up on the inside of each section, about 12 in. from each bulkhead. The object of this is, to prevent the water which flows through the bolt holes finding its way into the body of the compartment, it being by this system confined entirely to the space between the bulkhead and the high floor. The sections when brought together can be readily

united by the men inside the sections passing bolts over the high floor and through the angle-iron frames. When the bolts are screwed up the water which has already found its way into the intermediate space between the bulkhead and the high floor is pumped out. By this system we are able to get the sections floatable and capable of being united together while afloat, and it is a work of great rapidity to connect up the different parts. I may mention that we have built a large number of these steamers. Four we sent away last month to East Africa for the Portuguese Government. As evidence of the rapidity with which they can be put together, we had the pleasure some years ago of building two for the British Government. The contract was to put one of the boats together and have steam up in twenty-four hours. The authorities desired us to try the experiment to prove that we could carry out what we had undertaken. We had the sections and all the different parts placed before us in pieces in the same state as they would be discharged from the vessel taking them out. We started at six o'clock in the morning, and we had the boat under steam by one o'clock the same day. I merely mention this as evidence of the rapidity with which boats, built on this system, of about 100 ft. in length, can be put together in distant parts of the world. I thought this explanation would interest the French members of the Institution, especially as it is the system which we adopted in the construction of the *Opale*.

Mr. R. J. Quelch (Member): My Lord, before Mr. Martell rises to reply, I should like to make a few remarks. Having had some experience of light-draught steamers, and having designed two steamers now running between London and Paris—the only two steamers in the United Kingdom that have run this service regularly for some years—and having now some definite experience of the behaviour of those steamers, I should like to say, with regard to the remarks that fell from Mr. Denny, that he rather wished that Lloyd's Society had had nothing to do with light-draught steamers, that my experience is just the reverse of his. When, about six years ago, I designed the first steamer for running between London and Paris, it was said that as she was a boat mainly intended for traffic in the Thames and Seine, she ought to be made much lighter than Lloyd's scantlings; but, considering that she would have to cross the Channel—and I have unfortunately been in some very severe gales in the Channel, quite as severe as you often encounter in the Atlantic—I concluded, rather than that this ship should be often taking shelter, she should be built in excess of Lloyd's requirements for their 100 A1 class, so as to enable her to face heavy Channel gales, and I fancy that I had some conversation with my friend Mr. Martell about the matter, and he concurred in the wisdom of my decision. When one further considers the difficulties of the navigation of the Seine, which lead to ships often going aground in a very unforeseen way, I feel now, with my wider experience, that I acted judiciously in putting extra strength into the boat beyond Lloyd's rule. I made the bulkheads thicker, the longitudinal strength greater and stronger than Lloyd's rules in other ways that I need not now trouble you with. What has been the result? Why that, although this steamer has frequently taken the ground, and been subjected to great strains, she has done her work with very little cost to the underwriters. When, some two years ago, I designed the second steamer, with the distinct advice either of my friend Mr. Martell, or of Mr. Cornish, I still further increased the scantlings beyond Lloyd's rules, as the experience I had gained from the running of the first steamer pointed to the advisability of such a course. Now, sir, I am quite satisfied that, if I had not had the support of Lloyd's in the strengthening of these steamers, the tendency both of the shipowner and the builder would have been to lighten the steamer, and it is now generally acknowledged that without the extra strength added the results would have been most unsatisfactory. I am quite satisfied that underwriters, by having Lloyd's Society to refer to in the way of classification, are greatly benefited.

In fact, I consider it would be a still greater benefit if Lloyd's would clearly indicate in their Register Book the extra strength to be given to such boats as I have been speaking about, as this, I think, would lead to its being regularly recognised that, steamers intended for river, and what is called inland, navigation ought to have extra strength, instead of less, as generally thought. I thought I would just make these few remarks to give the benefit of my experience to the members of the Institution, and to mark my strong disapproval of leaving the matter entirely in the hands of shipbuilders, and not subject in any way to proper rules of classification, such as Lloyd's apportion for light-draught steamers.

Mr. B. Martell (Vice-President): My Lord, Ladies, and Gentlemen, I am very much obliged to Dr. Elgar for his complimentary remarks, and I perfectly coincide with his opinions with reference to the necessity of the subdivision of vessels, having to carry passengers, by bulkheads to as great an extent as we can possibly get them. This can be done in passenger vessels to a much greater extent, of course, than in cargo-carrying vessels, because it does not interfere in any kind of way with the accommodation of the passengers, with the exception of the saloon. It was said you cannot carry the bulkhead up to the saloon deck, and if you do not do that it is not of much use. I noticed in one of the vessels referred to here, built by the Fairfield Company, of which Dr. Elgar is one of the directors, that a very ingenious application was made for doing this, and doing it very effectually, without interfering in any way with the saloon accommodation, and showing that really these vessels can be divided when it is necessary, and when the builder wishes to do so, fore and aft, in a most effective manner. No better example of the advantages of this could be given than that of another vessel, whose name has not been mentioned, built also by Dr. Elgar's company. That vessel, when she came round from the Clyde to the Thames, in tempestuous weather, got on shore, and she most undoubtedly would have become a perfect wreck, had it not been for the subdivision of bulkheads which was carried out, and which Dr. Elgar referred to. That vessel—I may mention it now—was the *Koh-i-Nor*. She would undoubtedly have gone to pieces, had it not been for the subdivision by bulkheads referred to by Dr. Elgar. I remember after the *Princess Alice* was lost, and the great sacrifice of life that occurred by that collision, attention was called to the necessity—the great desirability—of dividing these vessels—even small river vessels such as the *Princess Alice*—into a greater number of compartments by subdivisional bulkheads—additional bulkheads; and I remember a paper being read at the Institution of Naval Architects, when I made the remark that no difficulty existed, that I could see, why this could not be done. I see a gentleman in this company here who was one of the first to undertake doing that, and he is a member of the firm of Sir William Armstrong & Co., of Newcastle. I see Mr. Swann, one of the directors of that company, here, and I remember his coming to me with a drawing showing how he proposed to do this, and I perfectly agreed with him. We had some conversation on the subject, and they built that vessel—I think she was one of the first vessels running on the Thames with divisional bulkheads carried out in that manner. That it is a most desirable thing no one can doubt. If the Board of Trade, instead of some of the rules they feel called on to make, and which are not so essentially necessary, were to obtain a law that essentially passenger vessels should be so divided, I do not think they would go too far, and I think they would meet with public approval in doing so. Now, with regard to Mr. Denny—I always like to listen to the complimentary remarks of Mr. Denny. I may tell you I have a great respect for Mr. Archibald Denny, and I have a great respect for his firm. I think there is nothing like being told the truth fairly and squarely and having it out. Mr. Denny comes forward boldly and tells you what he means. When that is done we can grapple with such remarks, and, although we may not be able to make a satisfactory explanation, still we have an opportunity of endeavouring to do so. Now I think Mr.

Denny, in the first place, is wrong in his comparison of the boats on Plate XII. and on Plate XVII.; they are very dissimilar, and they are intended for different trades. One is intended essentially for river service, where there is nothing but smooth water, and consequently the scantlings can be made very light; the other vessel is running where she has to encounter sometimes very heavy seas, and the question, as Mr. Quelch said, comes to this—whether you can, under such circumstances, much reduce the scantlings, even from what you require for an ordinary cargo-carrying vessel. That is why the scantlings here between these two vessels differ to a considerable extent, as referred to by Mr. Denny. There would be no necessity to go into this subject at all, were it not that we endeavour to apportion the scantlings according to the service in which the vessel will be engaged and the proportions of stresses coming on vessels under such circumstances. Therefore that accounts for the difference between these two vessels referred to.

Mr. A. Denny: I was under the impression that the ships on Plate XII. were the *Eolo* and *Venus*, built by us.

Mr. Martell: You are wrong, sir, as regards your comparison of the vessels on Plate XII. and Plate XVII. I am very sorry that I have met with the disapproval of Mr. Denny in bringing forward this paper.

Mr. A. Denny: Not at all. I must protest against that.

Mr. B. Martell: Then I may say that, when one tells me that it is to be deplored that such a paper has been produced, I naturally think he is dissatisfied with it——

Mr. A. Denny: I must protest. I never said I deplored it was produced—I said I deplored the necessity for Lloyd's having to do with these vessels.

Mr. B. Martell: I beg your pardon. I was going to say this: there is the old saying, "Hit high or hit low, some you never can satisfy, do what you will." I remember some years ago the remark was made, by Sir Edward Reed I think, that Lloyd's Register ought to place themselves more in the position of furnishing the information they possess to the general public. They are in the position of acquiring knowledge and information on all sorts of subjects. They can, at the same time, look at matters from both points of view, and therefore it is due to the public that they should endeavour to furnish them with all the information they can. I think this is the more necessary when you know that a great Department like the Admiralty has been sometimes criticised because they did not see the necessity of furnishing information to the general public on many matters of great interest affecting the subjects brought under their notice. They have, like other great bodies, adopted a different course, and have placed before the public now, very quickly, nearly all the results of investigations and experience they can, for the public good. I feel that it is necessary, and, in my opinion, it is good for the public generally, that Lloyd's Register Society, when there is a great general subject on which they can give information, involving many considerations and points of interest and illustrations which cannot be produced by private individuals, should come forward and let the public have them. Now, my Lord, I would say at the present day the schoolmaster is abroad. It is no use to hide yourself in your shell, and to suppose, like the ostrich, that if you put your head in the sand you will not be seen. The fact is there is nothing built in this country—I beg your pardon—I know nothing about any ship that is built in this country; but in my own country there is nothing built but what, within a very short time, I could give all the particulars of, if there was a necessity I should do so. But, as a rule, I feel it proper to be quiet, and here I have taken very

special care not to allude by name to any vessel. There are some drawings here in which, if I had thought proper, I could have extended very considerably the details of the information given, but I did not feel it right. I think there might be, in some cases of that kind, reasons for justifying the remarks of Mr. Denny, and therefore I did not do so. But here we have a pattern in Mr. Yarrow. Look at the difference between one who takes a narrow view of these things and one who is broad-minded, and can say this when asked for information : "Mr. Martell, you can have the whole of the information in my place," and who has furnished me with drawings and full detailed information. I could not take full advantage of his great kindness and liberality of mind, and place these before you ; therefore I have not done it, although it would have been exceedingly interesting if I had done so. I think Mr. Denny will excuse me when I say this, because, as a rule, he is very far from being narrow-minded in anything. Of course I do not use the words narrow-minded in the general sense in which those words are used. I can understand his special meaning when, for instance, his firm has worked up a particular description of vessel for a particular purpose of trade, when it has required a large amount of experience, and investigation of the subject, and scientific knowledge, to produce a structure which will fulfil the conditions, which are very many and very special indeed, and he considers it a speciality—he has built hundreds of vessels in that way—and he would not care to have it put before the public, and I should not think, if I had the means, of putting such information before the public. It is a very different thing to give illustrations of various vessels, for various purposes, when it is not a large part of a person's business to build such large vessels as that. I may say that I have placed nothing here before the public beyond what I have had sanction for doing, and I should not think of doing so, and if what I have given has been of any interest whatever, and will be of any value, I am exceedingly thankful for it. Mr. Denny, I may say, is quite mistaken in supposing that persons who wish to build such vessels as these only go to the very first-class builders who have a large scientific staff, where they can ensure the thing being done properly, and who have the highest reputation for turning out the best things. Nothing of the kind. We have vessels of this description built by every class of shipbuilder throughout the country. They are placed in the hands of some where the shipowners would not like to take the responsibility of having these vessels built, and, further than that, I know that they could not get them insured at anything like the same premium in all cases. I have underwriters coming to me, day after day, with regard to vessels of this kind, and they would not attempt to take them without getting my sanction that they were fit for their work, and therefore it becomes essentially necessary that there should be, for the benefit of the shipowner as well as for the builder and underwriter, such a society as Lloyd's Register Society, to deal with all types of vessels, and I trust they will always give all the information they can on all such subjects as those referred to. I do not say that I should have given Mr. Quelch the advice that he has acted on, although I may say with regard to his remarks that, when a vessel has to take the ground frequently, she should be much stronger than a vessel that never takes the ground ; and no doubt there is special strengthening required in such cases as that. That is the reason why small vessels, built for classification, have scantlings very much greater in proportion than large ones, not because they require it for longitudinal or transverse strength, but because they are continually taking the ground in rivers and similar places when loaded, and you have, therefore, to provide for that. I am much indebted, gentlemen, for the reception which you have given to my paper.

P.S.—It appears that there is a general feeling that I meant to imply that Mr. Denny was wrong in identifying the vessel on Plate XII. as the *Eolo*. I wish to correct that. Mr. Denny was perfectly

correct. What I intended to convey was that Mr. Denny was wrong in thinking that the trade the *Eolo* is engaged on was similar to that of the vessel on Plate XVII., and, with Mr. Denny's concurrence, I have made this clear in the printed discussion.

The President (the Right Hon. Lord Brassey, K.C.B.): Gentlemen, I am very sensible that your minds are in a high state of tension and excitement, in consequence of the debate which has arisen; but I am sure you are not so discomposed as to forget your duty to Mr. Martell, which I will undertake on your behalf, and that is, to thank him for his paper. Whatever you may think of the merits of the controversy, and whether or no you can, by a flight of imagination, bring yourselves to compare Mr. Martell to an ostrich, I do not know; but I am sure that you will be able to sympathise with him in his position, and to quite appreciate this—that high and exalted as is the position which Mr. Martell occupies, he is after all, a creature of circumstances.

ON COUPLING BOILERS OF DIFFERENT SYSTEMS.

By Monsieur Pierre Sigaudy, Engineer-in-Chief of the Société des Forges et des Chantiers de la Méditerranée; Member.

[Read at the Summer Meeting of the Thirty-sixth Session of the Institution of Naval Architects, June 12, 1895; the Right Hon. Lord Brassey, K.C.B., President, in the Chair.]

Although water-tube boilers may offer great advantages, they do not seem to many people trustworthy enough to be exclusively employed in a great number of cases. The plainest manner to convince those who are frightened is, I think, to fit effectually together the old and new system of boilers on the same ship, thus giving the possibility of getting up steam quickly, which is generally of great importance. This idea has been treated lately by *Engineering* with a view to Navy use; and it is no longer a mere project, as a trial has recently been made successfully by the Société des Forges et Chantiers at Havre on the tug-boat *Adour No.* 3, built two months ago for the "Chambre de Commerce of Bayonne." In this boat steam was produced by two boilers of quite different systems, one boiler being of the common return-tube type, and the other a water-tube boiler of the Normand system.

This tug has independent paddle wheels with fixed blades; the wheels may be connected or disconnected under way.

The main dimensions are:—

	Ft.	In.
Length between perpendiculars	118	1
Breadth	23	7¼
Depth moulded	13	1½
Draught on trial	8	0½
Power of the engines (about)	700 I.H.P.	
Weight on board { Coal in bunkers, 16 tons; Crew, tow-rope, &c., 2 tons }	18 tons	

The conditions of trial were:—Speed of 11 knots during six hours, the coal consumption not to exceed 2·1 lbs. per horse-power per hour. The getting up steam to be made within thirty minutes; of course it is most important for a tug-boat to get steam up as quickly as possible, especially when employed on salvage service.

This last condition has compelled us to put on board two different kinds of boilers; one of the Normand type, and one return-tube boiler of the ordinary type. We would rather have coupled two Normand boilers had not the owners asked that at least one of the two should be of the usual type, as they feared for the results of two water-tube boilers.

The principal dimensions of the engines and boilers are:—

	Pressure	114 lbs. per sq. in.
Normand boiler.	Grate surface	34·70 sq. ft.
	Heating surface	1,560·20 sq. ft.
	Steam space	32 82 cub. ft.
	Water volume	82·58 cub. ft.
Return tube-boiler.	Grate surface	38·73 sq. ft.
	Heating surface	1,232·55 sq. ft.
	Steam space	176·45 cub. ft.
	Water volume	345·13 cub. ft.
	Number of engines...	2

Type of ditto :—Compound, two cylinder, inclined, the two engines being coupled together in the centre of the shafting.

	Ft.	In.
Diameter of high-pressure cylinders	1	$10\frac{13}{16}$
Diameter of low-pressure cylinders	3	$3\frac{3}{8}$
Stroke	3	$7\frac{5}{16}$

The wheels with fixed blades have an external diameter of 16 ft. $1\frac{5}{8}$ in.

The general arrangement is a very disadvantageous one for the working together of two different boilers on the same set of engines. The whole is contained, as usual, in three different compartments divided by two water-tight bulkheads.

The boiler of the Normand type is placed in the forward compartment, with its funnel forward and stokehold aft; the engines are in the centre compartment, and the after compartment contains the return-tube boiler, with its stokehold placed forward. No special arrangement has been made for the steam and feed pipes, one single steam pipe making the communication between the two boilers, through the engine-room, with a branch to each engine. In the same way, the feed pipe is common to both boilers, and communicates with two independent feed pumps placed on the side of the engine-room, each one of which is sufficient to feed the two boilers. A single pump was working during the trials.

During the preliminary, as well as the official trials, the working of the boilers gave no trouble, the pressure remaining steady; no difficulty was found with the feed, whether the engines were worked connected or disconnected, the one ahead, the other astern, the one at rest and the other running, just as the owners (who wanted to be quite sure about the general working conditions of a tug-boat) gave their orders.

The time for getting up steam with the Normand boiler was, in the two trials, from 22 to 23 minutes. At the official trial for coal consumption, which lasted for six hours, the mean speed being 11 knots and the mean power 673 I.H.P., with 29·5 revolutions per minute, the consumption of coal was 1·81 lbs. per horse-power per hour, the fuel used having been briquettes d'Anzin.

The engines, running at full speed, indicated 731 I.H.P. The quantity of coal burnt in each boiler was pretty nearly the same on each trial.

These results seemed to me worthy of notice, as they prove that, it is easy to combine on board a ship water-tube boilers of the Normand system, or any other analogous type, with return-tube boilers, as this was carried out under most difficult conditions—that is to say, coupled and in separate stokeholds. Therefore, the dislike which certain owners profess towards them, on account of the fear they entertain of difficulties in working, is unjustified. I need not otherwise enumerate here all the advantages which those new boilers present, as compared with the return-tube boilers.

DISCUSSION.

Mr. J. I. Thornycroft, F.R.S. (Vice-President): My Lord, Ladies, and Gentlemen, I have much pleasure in making a few remarks on the present paper, because I feel it a pleasant duty to compliment M. Sigaudy on the paper. He gives us a very clear account of an experiment which, I think, is one of considerable interest at the present time. It may be described as one in which the battle of the boilers is being fought; and in England we have, I think, a change of opinion in progress in favour of the water-tube boiler. But, as suggested by M. Sigaudy, where people are timid and afraid of making an experiment, by introducing gradually in this way the tube boiler in competition with the ordinary boiler, the difficulty is overcome gradually instead of by a revolution. I do not fear at all that the competition will end in favour of the latter, and therefore I am glad it has been made. The experiment, as described, shows that the two boilers can be worked satisfactorily together. The tube boiler described is similar to one with which I am well acquainted. It does not contain that element which has been introduced into the Belleville boiler, viz., that the rate of emission of the steam from the boiler is regulated by a reducing valve; but in this case I believe the boiler is connected, as in the case of an ordinary one, direct to the steam pipe, and the changes of pressure, due to the sudden taking of steam by the engines, do affect the pressure in the boiler, whereas in the Belleville boiler that change of pressure is more limited; consequently this boiler requires larger separating vessels than are found necessary in boilers of the Belleville type. In our works we have tried a similar experiment, in which we have introduced a tubulous boiler in conjunction with other boilers, and the facility for getting up steam rapidly with one boiler is of value. The change in the rate of working can also be made very rapidly in the tubulous boiler. When steam hammers are taking steam from the common steam pipe, we have the advantage of the large boiler of the old type, containing a large amount of water, and forming, as it were, a fly-wheel to take up the rapid changes in the rate of working. It is interesting to me to hear of this experiment described by M. Sigaudy, because here he had an engine running at a slow speed, and consequently taking steam in larger volumes, at a time, than is usual in the practice we have had with tubulous boilers, because our

experience has been limited to circumstances where the engines have been running so fast as to make the emission of steam from the boiler almost constant. Some experiments have been made by the Chief Engineer of the Danish Navy upon this subject; there it was feared that running at a lower number of revolutions might affect the working of the boilers. I think if M. Sigaudy could give us some experience as to the effect of running the engines only with the Normand boiler, that would be of interest as elucidating this question, and I would beg to ask if he could make any such additions to his paper. I think we are all indebted to M. Sigaudy for his communication to the Institution.

Mr. A. F. Yarrow (Member of Council): My Lord and Gentlemen, this is a paper which, although short, is of very special interest, because I believe it is not impossible that the system described may be capable of more extensive adoption than is evident at first sight. The return tubular boiler is one which can be worked by ordinary stokers, and without much strain and without special anxiety about the water level. On the other hand, there is an enormous saving in weight in adopting the water-tube boiler, such as is being made at the present time, with very high steam generating powers. It may perhaps interest the meeting to know that the Dutch Government are building three cruisers at the present time of 9,000 H.P. each, and are adopting boilers of two distinct types in each vessel. They are providing 2,500 H.P. by means of ordinary return tubular boilers, and 6,500 H.P. by means of boilers of the type which my firm constructs, being of the water-tube type with straight tubes. The return-tube boilers will be used for cruising at slow speeds, and the water-tube boilers will be brought into action when a high speed is required. I simply mention this, as a combination of two distinct types of boilers in the same vessel, which seems to me to offer special advantages, and a very safe step to take at the present stage of the introduction of water-tube boilers. As we have here a very distinguished French authority on this subject, I think it would be very interesting if he would favour the meeting with a few remarks as to his opinion upon the combining of two different types of boilers, as foreshadowed in this paper; and also what system he would consider most suitable (if he does not mind expressing his opinion) for the fitting of these boilers, so that there would be as little anxiety on the part of the stokers as possible—of course, combining with the feeding arrangements, the system of which M. Normand has been the principal promoter, namely, heating the feed water before it enters the boilers. I am sure if M. Normand would make a few remarks on that subject it would greatly interest the meeting, because anything he says will be received as of very great value and importance.

Monsieur A. Normand (Member): My Lord, I have come forward on the invitation of Mr. Holmes, although I have very little to add to what has already been said about the combination of boilers. M. Sigaudy's experiment is most interesting. I quite endorse Mr. Thornycroft's opinion, that, on account of the extreme reluctance of shipowners to use water-tube boilers, the best way of forwarding their adoption is to place them on board of vessels together with others of the ordinary type, and M. Sigaudy is to be congratulated on being the first to have done so. It is most gratifying to hear that another experiment of the same kind is now being made by Mr. Yarrow in Holland.

The President: For large cruisers?

Monsieur Normand: Yes. As Mr. Yarrow has just pointed out, this new trial will be somewhat different in this, that the supply of steam will be continuous, whereas with the paddle engines there was, at each stroke, a large volume of steam taken from a very small steam chest. In spite of this drawback I can bear my testimony to the success of M. Sigaudy's experiment.

Sir William White, K.C.B., LL.D., F.R.S. (Vice-President): My Lord Brassey, Ladies, and Gentlemen. In the absence of my friend the Engineer-in-chief of the Navy, I just want to say two words. First of all, as a matter of fact, I may inform the Institution that in the designs for the *Powerful* and the *Terrible* the suggestion—which was not made in the public press till long afterwards, and in the course of the discussion, on our use of a particular type of boilers in those ships, namely, that we should associate the return-tube boiler with the water-tube boiler, and should have a portion of the power in one form of boiler and the balance in the other, was most carefully considered as one of the preliminaries. The design was worked out to the utmost detail, and after full consideration, was not adopted. The whole policy of the Belleville boilers in those large cruisers has been, as every one knows, fully discussed. I do not propose to enter into that discussion in the least, but I want to say that the consideration of the joint use of the two types of boilers was carried out most fully, plans were drawn in the greatest detail, but for reasons, which I will not now specify, the combination was not adopted. We were led to that in the most natural way. It is well known to the members of this Institution that there are already in existence warships of great power, in which a portion of the power is supplied by locomotive boilers, and a portion by boilers of the ordinary return-tube type. My friend Sir Nathaniel Barnaby sits there, and I can say, as I have said before, that in anticipation of any practical use being made of that idea, and while having the honour of being one of Sir Nathaniel Barnaby's assistants, I made such a proposal, to use the locomotive boiler in association with the return-tube boilers. Ships were designed on that basis, and had it not been for a trouble which arose in the *Polyphemus*, fitted with locomotive boilers, we should have had, in the British Navy, ships similar to those to be found in the Italian Navy. The *Lepanto* is a great example of that combination. We are greatly indebted to M. Sigaudy for giving us these facts; because, after all, facts are of immense value in a matter of this nature. The experiment has been necessarily limited in its scale, but it has been in many other particulars a trying one, and on behalf of the English members of the Institution I join in thanks to M. Sigaudy.

Monsieur P. Sigaudy (Member): I thank Mr. Thornycroft, Mr. Yarrow, Mr. Normand, and Sir William White for their kind remarks on the paper which I have had the honour of reading. The experiment of the coupling of boilers of different types appeared interesting to me, as proving that water-tube boilers could be run, in practice, with as much ease as those of the return-tube type. But evidently, it also proves that boilers of these two different types can be coupled, in practice, if there is any advantage in so doing. Mr. Thornycroft has asked if any comparative experiment was made to test the fuel consumption in the two types. In fact, such an experiment would have been conclusive in demonstrating the superior economy of the water-tube boiler, since one could, on the same boat, have caused the engine to run with each boiler successively. I should have liked to have made this test, but it was not possible to do so. We are shipbuilders, and in the delivery of our boats we are always tied by considerations of time and of cost. However, I will inform the President of the Bayonne Chamber of Commerce of Mr. Thornycroft's wish, and, if I can obtain precise information on the subject of the fuel consumption in each of these boilers, I shall have much pleasure in communicating it to the Institution of Naval Architects. In conclusion, I beg to thank the Meeting for the favourable reception which it has given to the paper which I have had the honour of reading.

The President (the Right Hon. Lord Brassey, K.C.B.): In your name, gentlemen, I thank M. Sigaudy for his extremely valuable contribution to the papers of this morning.

PRELIMINARY PROCEEDINGS.

THURSDAY MORNING, JUNE 13, 1895.

The following gentlemen having been duly recommended by the Council were unanimously elected as Members of this Institution:—Mr. Robert Carson, Marine Superintendent and Consulting Engineer, Hull; Mr. Robert Cooke, of the Hong Kong and Whampoa Dock Company Limited, Hong Kong; Mr. Robert Farquhar, Shipyard Manager to Messrs. Day, Summers & Co., Southampton; Mr. Hugo Pinkney Frear, Chief Draughtsman to the Union Iron Works, San Francisco, Cal., U.S.A.; Mr. Albert Scarfield Jackson, Consulting Engineer and Marine Surveyor, Cardiff; Mr. Joseph Hamilton Linnard, Superintending Constructor U.S. Navy, Washington, D.C., U.S.A.; Mr. John Maccoy, Consulting Engineer, Newcastle; Mr. James Mackenzie, Chief Draughtsman to Messrs. David Rollo & Sons, Liverpool; Mr. Joshua Maddison, Marine Superintendent to Messrs. Joseph Wilson & Co., West Hartlepool; Herr Joseph L. Meyer, of Papenburg, Hanover; Mr. Richard Morrin, Superintendent Engineer to Messrs. Lamport & Holt, Liverpool; Mr. William Harvey Orvis, Senior Partner in the firm of Messrs. Orvis & Fuller, Ipswich; Mr. James Gardner Reid, Chief Draughtsman to Messrs. Lobnitz & Co., Renfrew, N.B.; Mr. Alexander Rolland, Technical Adviser to the Royal Hungarian Sea Navigation Company "Adria," Limited, Fiume; Mr. James Rowan, partner in the firm of Messrs. David Rowan & Son, Glasgow; Mr. Charles Edward Smith, Marine Superintendent to Messrs. Rickinson Son & Co., West Hartlepool; Mr. John Spear, Superintendent to Messrs. T. Wilson, Sons & Co., Hull; Mr. James MacIntyre Thomson, of Great Western Road, Glasgow; Monsieur Léon Vivet, of the Bureau Veritas International Register of Shipping, Paris.

The following gentlemen were elected Associates:—Mr. Thomas James Collis, Mr. James Herbert Cory, Mr. William Henry Devine, Mr. John A. E. Etherington, Lieutenant D. C. Garcia (Argentine Navy), Mr. Patrick Gardner, Mr. Frank Glenfield, Mr. W. Miall Green, Mr. A. F. Houlder, Mr. Walter C. Hume, Monsieur M. Jullien, Captain the Hon. Hedworth Lambton, R.N., Mr. Samuel Lloyd, Sir William G. Pearce, Bart., M.A.L.L., M.P., Mr. Thomas H. Nelson, Mr. G. Renwick, Mr. Arthur Ritson, Captain M. H. Riall Sankey, R.E. (retired), Mr. S. Vassilioff, Mr. Edward Vernon, Mr. M. R. Webster, Mr. R. W. Williams, Captain Arthur K. Wilson (Royal Navy), Mr. Herbert C. Wilson.

Mr. B. Martell (Vice-President): Gentlemen, I have the honour to propose for your consideration the following alterations in the Rules of the Institution:—First, to alter Rule 1 by omitting the words "and honorary associates"; secondly, to substitute for the existing Rule 4 the following: "The class of honorary members shall consist of persons on whom the Council shall see fit to confer an honorary distinction"; and thirdly, to expunge Rule 5 and renumber the remaining rules. I may

say that the object of this proposal is to enable the Council to have a little more scope in conferring honours on distinguished persons and others. At the present time the rule is a hard and fast one, and it is very difficult indeed for the Council to select any person whom they think fit to honour by electing them as honorary members. It is just following in the steps of other great institutions similar to the Institution of Naval Architects, and therefore may not be considered as progressing too fast in any way, and I think it will meet with your acceptance. I have the honour to propose these resolutions.

Mr. F. C. Marshall (Member of Council): I have great pleasure in seconding the alterations suggested by Mr. Martell.

The resolutions having been put to the meeting, were carried unanimously.

THE COST OF WARSHIPS.

By Francis Elgar, Esq., LL.D., F.R.S.E., Vice-President, late Director of H.M. Dockyards.

[Read at the Summer Meeting of the Thirty-sixth Session of the Institution of Naval Architects, June 13, 1895; the Right Hon. Lord Brassey, K.C.B., President, in the Chair.]

An account has recently been presented to Parliament by the Admiralty under the provisions of the Naval Defence Acts, 1889 and 1893, which shows the expenditure up to March 31, 1894, on each of the vessels built under those Acts and on its armament. The Report of the Comptroller and Auditor-General, Sir Charles L. Ryan, upon this account has been presented with it; and it is pointed out in the Report that, "a sufficient number of vessels of similar types, built by contract and in Her Majesty's Dockyards, respectively, have now been completed to enable some comparison to be made between the two sets of cost results"; and also that "for the first time a standard, imperfect though it may be, appears to be available by which to test the working results of Her Majesty's Dockyards."

The Comptroller and Auditor-General appends to his Report a statement of the aggregate cost of each Naval Defence ship completed on March 31, 1894, which is here given in Appendix I. He says with reference to this statement:—"The comparative results show that Dockyard shipbuilding is more favourable in the case of first-class battleships, but not so economical, so far as can be judged by aggregate cost, under the other types; while it is noticeable that Dockyard results under the same types vary considerably *inter se*."

The cost accounts of the ships built under the Naval Defence Acts above referred to furnish data such as have not been available before for analysing and comparing the costs of warships of different classes. It is the first time, as the Comptroller and Auditor-General points out, that a standard of comparison has been available; and it is fortunate that in now applying this standard we find a much greater number of similar ships appropriate for the purpose, built at the same period in the various Dockyards and by contract, than could have been brought together at any former time.

The system of accounts formerly in use in H.M. Dockyards did not furnish the data requisite for analysing in detail the cost of work upon a new ship, or for com-

paring the cost of similar work in different ships and at the different Dockyards. The labour costs were made up in the department which carried out the work; and the whole labour expenditure upon a ship was brought together in the Chief Constructor's office, and distributed over various groups or items in an account called the grouping account. The preparation of this account was a very tedious and complicated affair; and, when complete, it did not present the costs of labour, incurred upon the various sections of work, in a manner which enabled the wages expenditure to be properly examined, or to be compared or judged of, in detail. The wages accounts for one ship could not be—and were never attempted to be—used for estimating in detail the cost of wages in other ships; and the system of grouping was of no practical value, notwithstanding that a great amount of clerical work was expended upon it.

The accounts of cost of the materials charged to the building of a ship were kept quite independently of the departments that kept the cost of labour, and prepared the "grouping account" of labour. The whole of the accounts relating to materials were kept in the Accountant's Department; and the cost of materials was grouped upon a different system altogether from that of the labour. The result was that even if the wages expenditure had been grouped in a practical and useful way, it would still have been impossible to obtain the cost of any specific portion or department of the work from the accounts, because the grouping of the materials expenditure differed from that of the wages in every particular.

These accounts were abolished in July, 1887, and a new system was adopted, which resembles, in its main features, that employed in the principal private shipbuilding yards. The leading private shipbuilders, those who build warships for the Admiralty and Foreign Governments, and others who only do mercantile work, gave the benefit of their experience most freely and generously to the Admiralty officers who were charged with the duty of improving the cost keeping and estimating in the Dockyards. They allowed the Accountant-General of the Navy and the Inspector of Dockyard Accounts to go through their offices, and see for themselves how few clerks are necessary to keep accounts which it was at first feared at the Admiralty would cost more for clerical work than they were likely to be worth. The works thus visited, at which the particulars of cost keeping, time-keeping, &c., were freely placed at the service of the Admiralty officers, were those of Messrs. J. & G. Thomson, Clydebank; the Fairfield Shipbuilding and Engineering Company, Messrs. R. Napier & Sons, Messrs. Wm. Denny & Bros., Messrs. Sir W. Armstrong & Co., the Palmer Shipbuilding Company, Messrs. Harland & Wolff, and the Barrow Shipbuilding and Engineering Co.

The improved system of accounts finally adopted by the Admiralty differs in details from that of any of the private yards named; but the principles on which it is based

are similar. They enable the costs of the different sections, or departments, of the work to be judged of when a ship is completed, and the costs of different ships to be compared in detail. These cost accounts also furnish valuable data for estimating in detail the cost of new ships, and they enable the progress of expenditure upon the various parts of the work, and in the different departments, to be closely watched from week to week while a ship is being built.

In these accounts the costs are grouped under the various items or heads A to Z given in Appendix II. Each of these items is divided into a number of sub-heads; and the cost is kept separately for any or all of these sub-heads, as may be decided when the account for building a ship is opened. For example, "Item A: Forgings and Castings" is subdivided as follows:—

A1. Stem.
A2. Stern post.
A3. Shaft brackets.
A4. Rudder frame.
A5. Boss pieces, and other large structural forgings and castings.
A6. Forgings and castings for turrets and turntables.

The cost of materials is, of course, charged to the same item as the wages expended upon them, so that the expenditure upon materials and wages under any head or sub-head of the account can be known.

At the same time that the Dockyard cost accounts were altered, the method of estimating for new ships was also altered, so as to put the estimating and the cost keeping upon the same basis, and keep the estimates and cost accounts in agreement on all points. This enables the various items and sub-heads of an estimate to be afterwards checked by the actual costs, and it ensures that the details of the cost accounts will furnish trustworthy data for subsequent estimates.

The proposals for these changes were made in June, 1886, and they were finally approved and brought into operation in July, 1887. The first ships to which they were applied were the first-class battleship *Trafalgar*, the second-class cruiser *Melpomene*, and the composite sloop *Nymphe*—all building at Portsmouth. The *Trafalgar* was at that time nearly half built and ready for launching. As soon as sufficient progress had been made at Portsmouth to show the practical working of the new system, officers were sent there from the other Dockyards to look into the details, and it was extended to ships of all classes at each Dockyard. The new system was not got into satisfactory working order everywhere so as to be of much practical use in estimating for new ships, or in judging of the cost of work in detail, till the ships built under the Naval Defence Act of 1889 came to be laid down. Hence the reason why, as the Comptroller and Auditor-General states, this is the first time a standard has been available for comparing the cost results of Admiralty shipbuilding.

There were seventy ships built under the Naval Defence Acts of 1889 and 1893,

viz., eight first-class battleships, two second-class battleships, nine first-class cruisers, twenty-nine second-class cruisers, four third-class cruisers, and eighteen torpedo gunboats. These were not all completed on March 31, 1894, so that the costs of some cannot yet be dealt with accurately upon the information contained in the published accounts. There were sufficient, however, already complete on the date named to furnish data for an instructive comparison of the costs of different types of warships, of similar ships built in the Dockyards and by contract, and of similar ships built in different Dockyards; and the Navy Estimates for the year 1894-95 give estimates of the cost of completing those that were not then out of hand.

The published accounts give the complete costs of five out of the e ght first-class battleships, two of which were built by contract and three in the Dockyards; seven out of the nine first-class cruisers, three of which were built by contract and four in the Dockyards; twenty-one out of the twenty-nine second-class cruisers, seventeen of which were built by contract and four in the Dockyards; the whole of the four third-class cruisers, all built in the Dockyards; and eleven out of the eighteen torpedo gunboats, six of which were built by contract and five in the Dockyards. All the completed ships are included in the Comptroller and Auditor-General's comparison of cost given in Appendix I., except the four third-class cruisers, which were all built in the Dockyards. The figures given in this paper for the vessels not complete on March 31, 1894, will be taken, as stated, from the Navy Estimates for 1894-95.

I propose to analyse the costs of these ships, so far as that can be done, with the aid of the Dockyard Expense Accounts for 1892-93* and 1893-94* and the Navy Estimates. The following Tables A and B give the complete costs of the first-class battleships whose accounts had been closed on March 31, 1894, and the latest Admiralty estimates for those not quite finished on that date. These vessels are 380 ft. in length between perpendiculars, 75 ft. in extreme breadth, and are of 14,150 tons displacement. The thickness of armour at the waterline is 18 in. The total weight of hull, exclusive of machinery, equipment, &c., is about 9,640 tons, which includes about 3,200 tons for vertical armour, backing, &c.

The estimated expenditure upon the three ships *Repulse*, *Revenge*, and *Royal Oak*, that were incomplete on March 31, 1894, may not be exact, but the corrections that might afterwards be made for actual cost could not be sufficient to materially affect the average costs of the Dockyard ships and the contract ships. Taking the figures for average cost, therefore, as in the Tables, it will be seen that the direct charges for hull, fittings, and equipment, amount to £592,704 in the Dockyard ships, and £682,978 in the contract ships. Deducting the cost of vertical armour, which

* Parliamentary Papers, Navy, No. 42, March 24, 1894, and No. 60, February 21, 1895.

TABLE A.

First-class Battleships Built in the Dockyards.

Name of Ship.	Where Built. 1. Hull. 2. Machinery.	Direct Charges (Exclusive of Reserve Gun Mountings). Hull, Fittings, and Equipment. Labour.	Materials (net). Vertical Armour.	Materials (net). All other Materials.	Total.	Propelling and other Machinery.	Gun Mountings, Torpedo Tubes, &c.	Steam Boats.	Total of Direct Charges as per Naval Defence Account.	Incidental Charges.	Total Cost, including Incidental Charges.
		£	£	£	£	£	£	£	£	£	£
Hood	1. Chatham 2. Humphrys	200,822	265,000	129,504	595,326	101,743	78,253	8,446	783,768	62,531	846,299
Empress of India	1. Pembroke & Portsmouth 2. Humphrys	208,955	260,000	131,559	600,514	103,496	77,741	7,156	788,907	55,217	844,124
Royal Sovereign	1. Portsmouth 2. Humphrys	186,587	260,000	126,390	572,977	101,887	84,767	8,602	768,233	68,915	837,148
Repulse*	1. Pembroke & Portsmouth 2. Humphrys	206,365	260,000	135,635	602,000	102,139	80,363	5,515	790,017	56,772	846,789
Average of four Dockyard Ships		200,682	261,250	130,772	592,704	102,316	80,281	7,430	782,731	60,859	843,590

TABLE B.

First-class Battleships Built by Contract.

Name of Ship.	Where Built.	Direct Charges (Exclusive of Reserve Gun Mountings). Hull, Fittings, and Equipment. Contract. Hull, &c., ex. Vert. Armour.	Contract. Vertical Armour.	Dockyard Expenditure. Labour	Dockyard Expenditure. Materials (net).	Total.	Propelling and other Machinery.	Gun Mountings, Torpedo Tubes, &c.	Steam Boats.	Admiralty Inspection.	Total of Direct Charges as per Naval Defence Account.	Incidental Charges.	Total Cost, including Incidental Charges.
		£	£	£	£	£	£	£	£	£	£	£	£
Ramillies	Clydebank	409,551	260,000	10,863	12,311	692,725	101,202	77,901	9,415	8,007	889,250	10,071	899,321
Resolution	Palmer's	391,757	260,000	10,595	11,723	674,075	96,397	77,591	5,097	7,931	861,091	9,612	870,703
Revenge*	Palmer's	391,639	260,000	9,950	10,000	671,589	96,346	77,904	5,441	8,133	859,413	9,674	869,087
Royal Oak*	Laird Bros.	413,006	260,000	10,490	10,030	693,526	96,635	78,236	5,501	8,199	882,097	9,961	892,058
Average of four Contract Ships		401,488	260,000	10,474	11,016	682,978	97,645	77,908	6,363	8,068	872,962	9,830	882,792

* These ships were not complete on March 31, 1894. The figures relating to them are taken from the Navy Estimates for 1894-95 except those relating to steam-boats and Admiralty inspection, which are from the Dockyard Expense Accounts.

is supplied by the Admiralty in both cases, the figures become £331,454 for the Dockyard ships, and £422,978 for the contract ships, exclusive of vertical armour. These figures do not include incidental charges incurred at the Dockyards, which are of course much greater on the Dockyard ships than on the contract ships, as the above tables show.

The two second-class battleships were built in the Dockyards: one, the *Barfleur*, at Chatham, and the other, the *Centurion*, at Portsmouth. Their costs were not complete, however, on March 31, 1894; and, as there are no contract ships of the type to compare them with, they are now left out of consideration.

The following Tables C and D give the complete costs of the first-class sheathed cruisers, and Tables E and F those of the first-class unsheathed cruisers, whose accounts had been closed on March 31, 1894; and the latest Admiralty estimates for those not then complete. These vessels are 360 ft. in length between perpendiculars. Those that are sheathed are 60 ft. 8 in. in extreme breadth to outside of sheathing,

TABLE C.

First-class Sheathed Protected Cruisers, Built in the Dockyards.

Name of Ship.	Where Built. 1. Hull. 2. Machinery.	Direct Charges (Exclusive of Reserve Gun Mountings). Hull, Fittings, and Equipment. Labour.	Materials (net). Vertical Armour.*	All other Materials.	Total.	Propelling and other Machinery.	Gun Mountings, Torpedo Tubes, &c.	Steam Boats.	Total of Direct Charges, as per Naval Defence Account.	Incidental Charges.	Total Cost, including Incidental Charges.
		£	£	£	£	£	£	£	£	£	£
Royal Arthur	1. Portsmouth 2. Maudslay...	126,228	21,000	89,963	237,191	99,127	28,541	6,171	371,030	35,194	406,224
Crescent	1. Portsmouth 2. Penn.....	114,600	21,000	90,819	226,419	94,260	28,449	5,873	355,001	32,826	387,827
Average of two Dockyard Ships...		120,414	21,000	90,931	231,805	96,693	28,496	6,022	363,016	34,010	397,026

* The vertical armour includes armour-plating to engine hatch, casemates, conning tower, &c.

TABLE D.

First-class Sheathed Protected Cruisers, Built by Contract.

Name of Ship.	Where Built.	Direct Charges (Exclusive of Reserve Gun Mountings). Hull, Fittings, and Equipment. Contract.	Dockyard Expenditure. Labour.	Materials (net).	Total.	Propelling and other Machinery.	Gun Mountings, Torpedo Tubes, &c.	Steam Boats.	Admiralty Inspection.	Total of Direct Charges as per Naval Defence Account.	Incidental charges	Total Cost, including Incidental Charges.
		£	£	£	£	£	£	£	£	£	£	£
Gibraltar.....	Napier's	201,946	9,113	9,823	220,882	97,874	29,236	3,727	4,123	355,842	5,324	361,166
St. George* ...	Earle's.....	230,830	7,800	9,000	247,630	96,601	30,651	3,283	4,369	382,534	4,661	387,195
Average of two Contract Ships ...		216,388	8,457	9,411	234,256	97,238	29,943	3,505	4,246	369,188	4,993	374,181

* This ship was not complete on March 31, 1894. The figures relating to her are taken from the Navy Estimates for 1894-95, except those for steam-boats and Admiralty inspection, which are from the Dockyard Expense Accounts.

and are of 7,700 tons displacement; and those that are unsheathed are 60 ft. in extreme breadth, and are of 7,350 tons displacement. The total weight of hull, excluding machinery, equipment, &c., is about 4,435 tons for each of the sheathed ships, and 4,085 tons for each of the unsheathed ships.

The two contract ships *Gibraltar* and *St. George* have a flush upper deck, with a 9·2 in. gun forward; but the two Dockyard ships *Royal Arthur* and *Crescent* were fitted with a forecastle and two 6 in. quick-firing guns upon it, in lieu of the 9·2 in. gun forward. The extra cost of the forecastle and fittings of the Dockyard ships may be taken at £4,500.

TABLE E.

First-class Protected Cruisers (Unsheathed), Built in the Dockyards.

Name of Ship.	Where Built. 1. Hull. 2. Machinery.	Direct Charges (Exclusive of Reserve Gun Mountings). Hull, Fittings, and Equipment. Labour.	Materials (net). Vertical Armour*	Materials (net). All other Materials.	Total.	Propelling and other Machinery.	Gun Mountings, Torpedo Tubes, &c.	Steam Boats.	Total of Direct Charges as per Naval Defence Account.	Incidental Charges.	Total Cost, including Incidental Charges.
		£	£	£	£	£	£	£	£	£	£
Edgar	1. Devonport 2. Fairfield	131,929	21,000	72,862	225,791	103,264	31,262	3,997	364,314	43,884	408,198
Hawke	1. Chatham 2. Fairfield	125,339	21,000	76,666	223,005	102,565	34,632	4,365	364,567	31,698	396,265
Average of two Dockyard Ships		128,634	21,000	74,764	224,398	102,914	32,947	4,181	364,440	37,791	402,231

* The vertical armour includes armour-plating to engine hatch, casemates, conning tower, &c.

TABLE F.

First-class Protected Cruisers (Unsheathed), Built by Contract.

Name of Ship.	Where Built. 1. Hull. 2. Machinery.	Direct Charges (Exclusive of Reserve Gun Mountings). Hull, Fittings, and Equipment. Contract.	Dockyard Expenditure. Labour	Dockyard Expenditure. Materials (net).	Total.	Propelling and other Machinery.	Gun Mountings, Torpedo Tubes, &c.	Steam Boats.	Admiralty Inspection.	Total of Direct Charges as per Naval Defence Account.	Incidental charges	Total Cost, including Incidental Charges.
		£	£	£	£	£	£	£	£	£	£	£
Endymion	Earle's	209,185	8,315	8,017	225,517	94,532	29,842	3,918	3,799	357,608	5,029	362,637
Grafton	1. Thames 2. Humphrys	206,177	8,159	8,263	222,599	96,789	29,321	4,069	3,321	356,099	5,156	361,255
Theseus*	1. Thames 2. Maudslay	207,578	7,870	7,000	222,448	94,698	28,536	3,564	3,779	353,025	4,779	357,804
Average of three Contract Ships		207,647	8,114	7,760	223,521	95,340	29,233	3,850	3,633	355,577	4,988	360,565

* This ship was not complete on March 31, 1894. The figures relating to her are taken from the Navy Estimates for 1894–5, except those for steam-boats and Admiralty inspection, which are from the Dockyard Expense Accounts.

In comparing the costs of the sheathed ships with those of the unsheathed ones of the same class in Tables C to F, about £17,000 requires to be allowed for the cost of teak and copper sheathing, extra cost of brass stems and sternposts, &c.

The following Tables G and H give the complete costs of the second-class sheathed cruisers, and Tables I and K those of the second-class unsheathed cruisers,

TABLE G.

SECOND-CLASS SHEATHED PROTECTED CRUISERS OF "ÆOLUS" TYPE, BUILT IN THE DOCKYARDS.

Name of Ship.	Where Built. 1. Hull. 2. Machinery.	Direct Charges (Exclusive of Reserve Gun Mountings). Hull, Fittings, and Equipment. Labour.	Materials (net). Vertical Armour.*	All other Materials.	Total.	Propelling and other Machinery.	Gun Mountings, Torpedo Tubes, &c.	Steam Boats.	Total of Direct Charges as per Naval Defence Account.	Incidental Charges.	Total Cost, including Incidental Charges.
		£	£	£	£	£	£	£	£	£	£
Æolus	1. Devonport 2. Hawthorne	68,463	6,000	42,749	117,212	60,564	11 567	653	189,996	22,387	212,383
Brilliant	1. Sheerness 2. Hawthorne	69,554	6,000	43,685	119,239	60,368	10,477	668	190,752	25,805	216,557
Average of two Dockyard Ships...		69,009	6,000	43,217	118,226	60,466	11,022	660	190,374	24,096	214,470

* The vertical armour includes armour-plating round engine-hatch, conning tower, &c.

TABLE H.

SECOND-CLASS SHEATHED PROTECTED CRUISERS OF "ÆOLUS" TYPE, BUILT BY CONTRACT.

Name of Ship.	Where Built. 1. Hull. 2. Machinery.	Direct Charges (Exclusive of Reserve Gun Mountings). Hull, Fittings, and Equipment. Contract.	Dockyard Expenditure. Labour.	Materials (net).	Total.	Propelling and other Machinery.	Gun Mountings, Torpedo Tubes, &c.	Steam Boats.	Admiralty Inspection.	Total of Direct Charges as per Naval Defence Account.	Incidental Charges	Total Cost, including Incidental Charges.
		£	£	£	£	£	£	£	£	£	£	£
Indefatigable..	London and Glasgow Engineering Company.	95,086	3,268	4,857	103,211	66,466	9,126	622	1,058	180,483	2,380	182,863
Intrepid		95,087	3,240	5,138	103,465	66,591	9,002	616	1,261	180,935	2,349	183,284
Iphigenia		95,087	3,721	5,161	103,969	66,588	9,860	628	1,514	182,559	2,438	184,997
Pique.....	Palmer's	99,664	4,168	4,977	108,809	65,144	9,268	662	977	184,860	2,833	187,693
Rainbow		99,663	3,543	4,924	108,130	65,187	8,997	651	1,412	184 377	2,642	187,019
Retribution ...		99,662	3,710	5,325	108 697	65,208	9,036	646	1,574	185,161	2,685	187,846
Sirius..	1. Elswick 2. Maudslay	100,941	4,209	4,975	110,125	66,728	9,087	660	802	187,402	2,874	190,276
Spartan.		100,937	3,361	4,869	109,167	66,792	8,848	664	1,021	186,492	2,576	189,068
Average of eight Contract Ships		98,266	3,653	5,028	106,947	66,088	9,153	644	1 202	184,034	2 597	186,631

whose accounts had been closed on March 31, 1894. It is not stated that the *Sybille's* accounts were then finally closed; but, as nothing was provided for her in the Navy Estimates for 1894-5, it is assumed she was complete. These vessels are 300 ft. in length between perpendiculars. Those that are sheathed are 43 ft. 8 in. in

TABLE I.

SECOND-CLASS PROTECTED CRUISERS (UNSHEATHED) OF "APOLLO" TYPE, BUILT IN THE DOCKYARDS.

Name of Ship.	Where Built. 1. Hull. 2. Machinery.	Direct Charges (Exclusive of Reserve Gun Mountings). Hull, Fittings, and Equipment. Labour.	Materials (net). Vertical Armour.*	All other Materials	Total.	Propelling and other Machinery.	Gun Mountings, Torpedo Tubes, &c.	Steam Boats.	Total of Direct Charges as per Naval Defence Account.	Incidental Charges.	Total Cost, including Incidental Charges.
		£	£	£	£	£	£	£	£	£	£
Apollo	1. Chatham... 2. Earle's.....	58,751	6,000	33,883	98,634	67,087	9,077	672	175,470	14,744	190,214
Andromache	1. Chatham... 2. Earle's.....	58,083	6,000	33,640	97,723	67,093	9,083	707	174,606	14,723	189,329
Average of two Dockyard Ships ...		58,417	6,000	33,762	98,179	67,090	9,080	689	175,038	14,734	189,772

* The vertical armour includes armour-plating round engine hatch, conning tower, &c.

TABLE K.

SECOND-CLASS PROTECTED CRUISERS (UNSHEATHED) OF "APOLLO" TYPE, BUILT BY CONTRACT.

Name of Ship.	Where Built. 1. Hull. 2. Machinery.	Direct Charges (Exclusive of Reserve Gun Mountings). Hull, Fittings, and Equipment. Labour.	Dockyard Expenditure. Labour.	Materials (net).	Total.	Propelling and other Machinery.	Gun Mountings, Torpedo Tubes, &c.	Steam Boats.	Admiralty Inspection.	Total of Direct Charges as per Naval Defence Account.	Incidental charges.	Total Cost, including Incidental charges.
			£	£	£	£	£	£	£	£	£	£
Latona	Barrow	93,507	2,334	3,433	99,274	61,652	9,085	521	564	171,096	2,155	173,251
Melampus	Barrow	93,523	2,991	3,720	100,234	61,590	9,058	616	671	172,169	2,233	174,402
Naïad	Barrow	93,460	2,659	3,826	99,945	61,672	8,773	619	846	171,855	2,142	173,997
Sappho	1. Samuda ...	88,726	2,543	3,889	95,158	67,109	9,169	645	1,766	173,847	2,141	175,988
Scylla	2. Penn	88,726	2,507	3,789	95,022	67,166	8,910	664	1,867	173,629	2,122	175,751
Sybille	1. Stephenson 2. Hawthorne	90,128	3,726	4,094	97,948	63,733	8,879	644	1,239	172,443	2,535	174,978
Terpsichore ...	Clydebank ...	89,910	2,334	3,653	95,897	66,790	9,810	647	714	173,858	2,050	175,908
Thetis	Clydebank ...	89,454	2,146	3,800	95,400	66,790	9,513	664	800	173,167	2,004	175,171
Tribune	Clydebank ...	89,453	2,071	3,763	95,287	66,739	9,456	676	844	173,002	1,975	174,977
Average of nine Contract Ships ...		90,765	2,591	3,774	97,130	64,804	9,184	633	1,034	172,785	2,151	174,936

extreme breadth to outside of sheathing, and are of 3,600 tons displacement; and those that are unsheathed are 43 ft. in extreme breadth, and are of 3,400 tons displacement. The total weight of hull, excluding machinery, equipment, &c., is about 1,940 tons for each of the sheathed ships, and 1,740 tons for each of the unsheathed ships.

The complete cost of each cruiser of this type is given in the Parliamentary return. They are similar ships, so that their costs can be compared. The average cost of hull fittings and equipment was £118,226 for the two Dockyard ships, and £106,947 for the eight contract ships. In comparing these figures with those for the unsheathed ships of the same class, about £10,000 requires to be allowed for the cost of teak and copper sheathing, extra cost of brass stems and sternposts, &c.

There are eight other second-class cruisers, which are of the *Astrea* type. These are of larger dimensions than the above. They are 20 ft. longer, 6 ft. more in breadth, and have two complete decks above the protective deck, instead of one complete main deck and a poop and forecastle as in the *Æolus* and *Apollo* types. The vessels of the *Astrea* type also carry two more 4·7 in. quick-firing guns than the others. They were all built in the Dockyards, but the complete cost of only one—the *Bonaventure*, built at Devonport—was made up to March 31, 1894, and they will not now be brought into a comparison of the cost of Dockyard ships.

Table L gives the complete costs of the third-class cruisers, which are not sheathed. They are 265 ft. in length between perpendiculars, 41 ft. in extreme

TABLE L.

THIRD-CLASS CRUISERS OF "PALLAS" TYPE, BUILT IN THE DOCKYARDS.

Name of Ship.	Where Built. 1. Hull. 2. Machinery.	Direct Charges (Exclusive of Reserve Gun Mountings). Hull, Fittings, & Equipment. Labour.	Materials (net).	Total.	Propelling and other Machinery.	Gun Mountings, Torpedo Tubes, &c.	Steam Boats.	Total of Direct Charges as per Naval Defence Act.	Incidental Charges.	Total Cost, including Incidental Charges.
		£	£	£	£	£	£	£	£	£
Pallas	1. Portsmouth 2. Hawthorne	45,944	27,506	73,450	55,365	7,662	633	137,110	13,295	150,405
Pearl	1. Pembroke... 2. Earle's ...	53,560	27,335	80,895	56,797	7,753	704	146,149	12,549	158,698
Philomel	1. Devonport 2. Earle's	50,119	26,082	76,201	56,310	7,898	661	141,070	16,438	157,508
Phœbe	1. Devonport 2. Devonport	52,082	26,491	78,573	51,119	7,158	672	137,522	24,756	162,278
Average of four Dockyard Ships		50,426	26,854	77,280	54,898	7,618	667	140,463	16,759	157,222

breadth, and are of 2,575 tons displacement. The total weight of hull, exclusive of machinery, equipment, &c., is about 1,250 tons.

There were no vessels of this class built by contract under the Naval Defence Act of 1889, but five similar ones were built by contract at about the same time, for the Australian Colonies, under the Imperial Defence Act of 1888. Although these are not included among the seventy ships authorised by the Naval Defence Act of 1889, a statement of their cost might be useful for comparison with the above. This will be found in the following table :—

TABLE M.

THIRD-CLASS CRUISERS OF "PALLAS" TYPE, BUILT BY CONTRACT FOR THE AUSTRALIAN COLONIES.

Name of Ship.	Where Built. 1. Hull. 2. Machinery.	Direct Charges (Exclusive of Reserve Gun Mountings). Hull, Fittings, and Equipment. Contract.	Dockyard Expenditure. Labour	Dockyard Expenditure. Materials (net).	Total.	Propelling and other Machinery.	Gun Mountings, Torpedo Tubes, &c.	Steam Boats.	Admiralty Inspection.	Total of Direct Charges as per Imperial Defence Account.	Incidental charges	Total Cost, including Incidental Charges.
		£	£	£	£	£	£	£	£	£	£	£
Katoomba	1. Elswick ...	61,785	—	—	61,785	44,643	10,565	—	1,745	118,738	—	118,738
Mildura.....	2. Hawthorne	60,819	—	—	60,819	44,637	10,518	—	1,462	117,436	—	117,436
Wallaroo	2. Hawthorne	60,815	—	—	60,815	44,644	10,593	—	1,409	117,461	—	117,461
Tauranga	Clydebank ...	68,879	—	—	68,879	49,068	10,780	—	2,113	130,840	—	130,840
Ringarooma.....	Clydebank ...	68,873	—	—	68,873	49,111	10,754	—	2,038	130,776	—	130,776
Average of five Contract Ships ...		64,234	—	—	64,234	46,421	10,642	—	1,753	123,050	—	123,050

We now come to the last of the vessels authorised by the Naval Defence Act of 1889—the torpedo gunboats, eighteen of which have been built. The two first, the *Gossamer* and *Gleaner*, were of 735 tons displacement, with machinery intended to develop 4,500 I.H.P. They were both built at Sheerness Dockyard. These were followed by eleven of the *Alarm* type, having 810 tons displacement. The machinery of ten of these is intended to give 3,500 I.H.P., and that of the other, the *Speedy*, is of 4,500 I.H.P. Five of these boats were built in the Dockyards, and six by contract. The remaining five of the torpedo gunboats were considerably increased in size. They have 1,070 tons displacement, and were all built in the Dockyards; but the cost accounts were not complete for any on March 31, 1894.

The only vessels of this class that can now be readily compared as regards cost are therefore those of the *Alarm* type. The figures relating to these are given in the following Tables N and O. These boats are 230 ft. in length, 27 ft. in extreme

breadth, and are of 810 tons displacement. The total weight of hull, exclusive of machinery, equipment, &c., is about 385 tons.

TABLE N.

Torpedo Gunboats of "Alarm" Type, Built in the Dockyards.

Name of Ship.	Where Built. 1. Hull. 2. Machinery.	Direct Charges (Exclusive of Reserve Gun Mounting). Hull, Fittings, and Equipment. Labour.	Materials (net).	Total.	Propelling and other Machinery.	Gun Mountings, Torpedo Tubes, &c.	Steam Boats.	Total of Direct Charges as per Naval Defence Account.	Incidental Charges.	Total Cost, including Incidental Charges.
		£	£	£	£	£	£	£	£	£
Alarm	1. Sheerness 2. Penn	17,456	9,437	26,893	22,949	5,387	438	55,667	6,730	62,397
*Antelope	1. Devonport 2. Yarrow	21,262	8,723	29,985	24,090	5,671	421	60,167	7,006	67,173
Circe	1. Sheerness 2. Penn	19,805	9,239	29,044	22,948	5,752	443	58,187	7,381	65,568
Hebe	1. Sheerness 2. Sheerness	19,444	9,506	28,950	26,616	5,595	431	61,592	12,207	73,799
Leda	1. Sheerness 2. Penn	16,998	9,416	26,414	23,319	5,720	436	55,889	6,750	62,639
Average of five Dockyard Boats		18,993	9,264	28,257	23,984	5,625	434	58,300	8,015	66,315

* The figures for *Antelope* are taken from the Navy Estimates for 1894-95, as she is not returned as complete in the Dockyard Expense Accounts for 1893-94; but the cost of steam-boats is added as in the Expense Accounts.

TABLE O.

Torpedo Gunboats of "Alarm" Type, Built by Contract.

Name of Ship.	Where Built.	Direct Charges (Exclusive of Reserve Gun Mountings). Hull, Fittings, and Equipment. Contract.	Dockyard Expenditure. Labour	Materials (net).	Total.	Propelling and other Machinery.	Gun Mountings, Torpedo Tubes, &c.	Steam Boats.	Admiralty Inspection.	Total of Direct Charges as per Naval Defence Account.	Incidental charges	Total Cost, including Incidental Charges.
		£	£	£	£	£	£	£	£	£	£	£
Jaseur	Barrow	23,847	797	1,057	25,701	17,758	4,726	427	846	49,458	726	50,184
Jason	Barrow	23,878	844	979	25,701	17,758	4,672	429	846	49,406	721	50,127
Niger	Barrow	23,848	659	948	25,455	17,756	4,634	429	846	49,120	681	49,801
Onyx	Laird Bros.	23,735	913	1,085	25,733	23,559	4,656	433	846	55,227	792	56,019
Renard	Laird Bros.	23,735	905	1,084	25,724	23,556	4,611	430	847	55,168	790	55,958
Speedy	Thornycroft	24,117	951	1,066	26,134	28,376	4,572	432	999	60,513	870	61,383
Average of five Contract Boats (excluding *Speedy**).		23,809	823	1,031	25,663	20,077	4,660	430	846	51,676	742	52,418

* The *Speedy* is excluded from this average because her machinery is 1,000 H.P. more than that of the other five boats, and her boilers are of a different type, viz., Thornycroft instead of locomotive.

Table P shows the average cost of the various classes of vessels included in the foregoing comparisons.

TABLE P.

AVERAGE COSTS OF THE DOCKYARD AND CONTRACT VESSELS OF VARIOUS CLASSES BUILT UNDER THE NAVAL DEFENCE ACTS OF 1889 AND 1893.

			DIRECT CHARGES (Exclusive of Reserve Gun Mountings).									
			Hull, Fittings, and Equipment.			Propelling and other Machinery.	Gun Mountings, Torpedo Tubes, &c.	Steam Boats.	Admiralty Inspection	Total of direct Charges as per Naval Defence Account.	Dockyard Incidental Charges.	Total Cost, including Incidental Charges.
			Hull, &c., ex. Vertical Armour.	Vertical Armour.	Total.							
			£	£	£	£	£	£	£	£	£	£
First-class Battleships	Dockyard	... ...	331,454	261,250	592,704	102,316	80,281	7,430	...	782,731	60,859	843,590
	Contract...	... ...	423,429	260,000	682,978	97,645	77,908	6,363	8,068	872,962	9,830	882,792
First-class Cruisers	Sheathed	Dockyard	210,805	21,000	231,805	96,693	28,496	6,022	..	363,016	34,010	397,026
		Contract	...	...	234,256	97,238	29,943	3,505	4,246	369,188	4,993	374,181
	Unsheathed	Dockyard	203,398	21,000	224,398	102,914	32,947	4,181	...	364,440	37,791	402,231
		Contract	...	...	223,521	95,340	29,233	3,850	3,633	355,577	4,988	360,565
Second-class Cruisers	Sheathed	Dockyard	112,226	6,000	118,226	60,466	11,022	660	...	190,374	24,096	214,470
		Contract	...	...	106,947	66,088	9,153	644	1,202	184,034	2,597	186,631
	Unsheathed	Dockyard	92,197	6,000	98,197	67,090	9,080	689	...	175,038	14,734	189,772
		Contract	...	...	97,130	64,804	9,184	633	1,034	172,785	2,151	174,936
Third-class Cruisers	Dockyard	... ...	...	...	77,280	54,898	7,618	667	...	140,463	16,759	157,222
	Contract...	... ...	...	...	64,234	46,421	10,642	...	1,753	123,050	...	123,050
Torpedo Gunboats	Dockyard	... ...	...	...	28,257	23,984	5,625	434	...	58,300	8,015	66,315
	Contract...	... ...	...	...	25,663	20,077	4,660	430	846	51,676	742	52,418

In the above tables, A to P, the expenditure under the head of "Hull, Fittings, and Equipment" is that incurred upon the building and fitting of the hull complete, and equipping it with masts, spars, derricks, anchors, cables, all boats except steam-boats, and everything except sea stores and consumable stores. That under the head of "Propelling and other Machinery" is for the propelling machinery, boat-hoisting engines and gear, electric light engines and dynamos, steam capstan and engines, steering engines, fan engines, and distilling machinery. That under the head of "Gun Mountings, Torpedo Tubes, &c.," is for hydraulic engines, piping, and mechanism for working turrets, turntables, and guns, and for lifting ammunition and projectiles; transferable gun mountings, torpedo carriages and tubes, and air-compressing machinery.

The amounts for "Dockyard Expenditure" added in the Tables to the cost of hull, &c., of the contract ships is for survey on receipt from contractors; docking and undocking; the supply of fire-hearths and cooking apparatus, anchors, cables, awnings, all boats except steamboats, &c., and copper sheathing for sheathed ships; fitting torpedo net defence and spare booms; cleaning and coating the bottom; painting the vessel inside and out; fitting coaling winches, torpedo tubes, gun mountings, &c.; stowing the warrant officers' and engineers' stores; making complete fitted drawings of the ship; landing, transporting, and shipping the guns; carrying out the steam, gunnery, electric light, and torpedo trials; and making such alterations or additions to the vessel as may have been ordered and not included in the specification, or arranged to be done by the contractors. These items of expense are included in the cost of the Dockyard ships.

The average amounts shown in Table P show the average costs to the Admiralty of the Dockyard-built and the contract-built ships respectively. They do not, of course, show the average costs of production, except as regards work done in the Dockyards. The expenditure upon hull, fittings, and equipment is the actual cost of the work in the case of the Dockyard ships; but in the case of contract ships the expenditure shown in the tables includes the unknown, but important, item of profit or loss to the contractors. This requires to be remembered in judging of the figures; because, although the costs to the Admiralty of the particular ships in question are not thereby affected, it must be obvious that if the amount of profit be unusually great, or there be a loss, upon certain contracts, it cannot be expected that differences between the cost of Dockyard ships and the cost to the Admiralty of contract ships, so far as these may be due to exceptional profits or to losses upon the contracts, will be permanent.

In comparing the costs of the Dockyard ships and the contract ships, there is no difference in the cost of the principal materials to the Admiralty and to contractors that could be allowed. The prices paid for steel, timber, and other large items were practically the same in both cases. I am also unable to ascertain that any important

allowance could be made for differences in the productive value of the wages paid to workmen. While these ships were in progress, I visited some of the principal private yards in which the battleships and cruisers were being built, and was allowed to look into what the labour was costing in the various departments; and, although there were differences in rates of pay, and especially in the individual earnings of certain classes of piece workers, I could not discover any great difference in the productive value of the labour as a whole. The absence of such difference was remarkable upon many items that could be easily checked, such as riveting, drilling, &c. The riveters, drillers, and other workmen in the private yards were earning higher wages than those in the Dockyards; but their output of work was greater, in about the same proportion as the wages were higher, in most of the cases I examined. There was so little difference upon the items I found it possible to check, that I did not feel able to point to any great advantage, on one side or the other, in productive value of the wages paid to workmen. I should add upon this point that there could be no question of any inferiority of workmanship in the contract vessels. The work could not be better; and the fact that it was all carried out under the critical eyes of Admiralty inspectors, who are not slow to condemn defective or doubtful parts, is a guarantee of its quality.

The differences of cost of work, whatever these may be apart from the profits or losses upon contracts, appear to be due, not very much to differences in prices of materials or rates of wages, but chiefly to the extent to which the various yards are laid out, and are equipped with machines and appliances, for performing this class of work with facility and economy, and at a minimum of expenditure for the transport and handling of materials, and the employment of labour upon them: and also to the good organisation of the labour with reference to the special requirements of the work, and its advancement in all the various departments or sections in such order and at such rates as contribute most effectively to the general progress and economy of the whole.

In comparing the average costs of the Dockyard and contract ships shown in the above tables, it is important that attention should be called to special circumstances that might affect the question of cost in particular cases. I will therefore proceed to do this, so far as my knowledge extends and I am free to use it. These remarks relate only to the expenditure upon hull, &c., as shown in the first four columns of figures in the preceding tables.

First-class Battleships.

The difference between the cost of the Dockyard ships and that of the contract ships is much greater in these than in any other class of vessels The average cost of the hulls of the four Dockyard ships was £331,454, exclusive of armour on belt, bulkheads, barbettes or turrets, casemates, and conning tower; as against an average cost of the four contract ships amounting to £423,429. These averages are not exact, because the figures

for one of the Dockyard ships, the *Repulse*, and those for two of the contract ships, the *Revenge* and *Royal Oak*, are based upon estimates. The estimates were made, however, in the beginning of 1894 when the vessels were almost complete, and the expenditure remaining to be incurred was very small; so that there could not be sufficient error in them to affect the present comparison. One of the Dockyard ships, the *Hood*, was a turret ship, and the others were all barbette ships; but this difference does not materially affect the cost of hull.

Each Dockyard ship of this class thus cost the Admiralty an average of £91,975 less, exclusive of incidental charges, than each of the ships built by contract. It is satisfactory that the Dockyard ships should be so much cheaper; but it should not be assumed that this rate of difference could be relied upon in future in building first-class

Battleships of "Magnificent" Class, Built in the Dockyards.

Name of Ship.	Where built. 1. Hull. 2. Machinery.	Direct Charges (Exclusive of Reserve Gun Mountings). Hull, Fittings, and Equipment. Materials. Vertical Armour.	All except Armour.	Labour.	Total.	Propelling and other Machinery.	Gun Mountings, Torpedo Carriages, and Gear.	Steam Boats.	Total.	Incidental Charges.	Total Cost, with Incidental Charges.
		£	£	£	£	£	£	£	£	£	£
Magnificent ..	1. Chatham... 2. Penn	292,750	141,735	207,245	641,730	90,885	101,585	6,000	840,200	72,227	912,427
Majestic	1. Portsmouth 2. Barrow.....	292,750	143,000	207,085	642,135	80,718	101,675	6,000	830,528	75,126	905,654
Average of two Dockyard Ships		292,750	139,768	207,165	641,933	85,301	101,630	6,000	835,364	73,677	909,041

Battleships of "Magnificent" Class, Built by Contract.

Name of Ship.	Where Built.	Direct Charges (Exclusive of Reserve Gun Mountings). Hull, Fittings, and Equipment. Contract. Armour.	Hull, &c., ex. Armour.	Dockyard Expenditure. Labour.	Materials.	Total.	Propelling and other Machinery.	Gun Mountings, Torpedo Carriages, and Gear.	Steam Boats.	Total.	Incidental Charges.	Total Cost, with Incidental Charges.
		£	£	£	£	£	£	£	£	£	£	£
Jupiter	Clydebank	292,750	352,118	10,000	10,000	667,118	86,933	99,342	6,000	859,393	20,590	879,983
Mars	Laird's	292,750	348,835	10,000	10,000	663,835	90,961	99,252	6,000	860,048	20,210	880,258
Average of two Contract Ships		292.750	350,477	10,000	10,000	665,477	88,947	99,297	6,000	859,721	20,400	880,121

battleships. This appears to be shown by the foregoing comparison of the estimated costs of the new battleships *Majestic* and *Magnificent*, building in the Dockyards, and the *Jupiter* and *Mars* building by contract. The figures are taken from the Navy Estimates for 1895-96: except those for vertical armour, which are from a Parliamentary Return of contracts recently entered into by the Admiralty, dated May 9, 1895.

It would thus appear that the difference between the cost to the Admiralty of Dockyard work and contract work has been reduced from £91,975 on the hulls of battleships of the *Royal Sovereign* type to £23,544 in the *Magnificent* type. Nothing that is known about the differences between the ships is sufficient to account for this amount of reduction, and I am unable to explain it. The builders of each contract ship of the latter type had completed one of the former not long before, and had her actual costs, and their experience in building her, to guide them in their estimates, so they ought to know what the vessel would cost. The same remark applies to the Dockyard ships. It may doubtless be assumed, even if the amount of reduction be too great to be permanent, that this reduced difference between the costs of battleships built in the Dockyards and by contract is nearer to what would generally be found in experience than the very great difference that resulted in the costs of the *Royal Sovereign* class. While the hulls of the Dockyard ships are each estimated to cost £15,479 more, on the average, than those of the *Royal Sovereign* class, the hulls of the contract ships are estimated to cost, on the average, £52,982 less. It cannot be assumed, whatever the explanation may be, that the reduced difference in the cost of the contract ships means a reduction of profit by that amount. It is only reasonable to suppose, however, that experience in the carrying out of this class of work, and the special facilities for performing it cheaply and quickly which are acquired by many who undertake it, lead to greater economy and despatch in private yards as well as in the Dockyards.

First-class Cruisers.

In dealing with the costs of this class of vessels, we require to make an allowance for the extra expenditure involved by the sheathing on four out of the nine that were built; and a further allowance for forecastles that were added to two of the number. The costs of the sheathed ships are given separately from those of the unsheathed ships in Tables C to F. There were two sheathed ships built in the Dockyards, and two by contract; and two unsheathed ships built in the Dockyards, and three by contract.

The average cost of the hull, fittings, and equipment of the two Dockyard sheathed ships was £231,805, and that of the two contract sheathed ships was £234,256. The two Dockyard ships were fitted with forecastles, and the others of the class were not. The extra cost of forecastle and fittings may be put down at £4,500, and this sum should be deducted from the average cost of the Dockyard sheathed ships when

comparing it with the costs of the others. This would make the average for the two Dockyard ships £227,305, as against an average of £234,256 for the two contract ships. The corresponding averages for the unsheathed ships are £224,398 for the Dockyard ships, as against £223,521 for the contract ships.

If we deduct the estimated extra expenditure involved by the sheathing, say £17,000, from the costs of the sheathed ships, we arrive at the amounts these vessels should have cost if they had been unsheathed, like the others of the class. This would be £210,305 for the two Dockyard sheathed ships, exclusive of sheathing, &c.; and £217,256 for the two contract ships. If we take the four Dockyard ships, two sheathed and two unsheathed, and deduct for the estimated extra cost of sheathing and forecastle in the sheathed ships, the average cost of the four Dockyard ships, exclusive of sheathing and forecastle, would be £217,352. Similarly, the average cost of the five contract ships, exclusive of sheathing, would be £221,017.

The cost to the Admiralty of the Dockyard ships of this class may thus be taken at an average of £3,665 per ship, exclusive of incidental charges, less than those built by contract. The three firms who built the contract ships complain, however, that they lost heavily over their contracts; and it is understood they have all made claims upon the Admiralty for compensation, and that the cases are now under arbitration. In view of this unknown factor of loss that is said to have been incurred upon all the contracts, it appears doubtful whether the costs of the contract ships could fairly be taken as a standard for comparison in dealing with this class. It seems probable that these costs are unduly low. On the other hand, the average cost of the Dockyard ships is unduly high The two sheathed ships, both built at Portsmouth, cost on an average, exclusive of extra expenditure connected with sheathing and forecastles, £210,305; but the two unsheathed ships, one built at Chatham and the other at Devonport, cost on an average £224,398. The two latter were commenced, and proceeded with for some time, under special difficulties with regard to carrying on the work, especially the one at Devonport. Those difficulties were afterwards removed so as to enable the work at those yards to be carried on more economically; and it would be found that the cost of building such ships soon became reduced. This is shown by the particulars given in Navy Estimates of other ships recently built. The cost of building a vessel of this class at any of the Dockyards named should not, in my opinion, now exceed that of the *Crescent*, the cheaper of the two Portsmouth ships, if the work were well looked after. The *Crescent's* cost was £204,919, exclusive of sheathing and forecastle.

As the average cost of the contract ships was £221,017, and losses are complained of upon all the contracts, it would appear that in view of the progress of improvement in the Dockyards, and the rate at which this class of ship could now be built,

the cost of a Dockyard ship should not much exceed ten per cent. less, exclusive of incidental charges, than that of a contract ship.

Second-class Cruisers.

There were two sheathed ships of this class built in the Dockyards and eight by contract, and two unsheathed ships in the Dockyards and nine by contract. The average cost of the hull, fittings, and equipment of the Dockyard sheathed ships was £118,226, or £108,226 exclusive of sheathing, allowing £10,000 for the extra outlay involved by sheathing. The average cost of the Dockyard unsheathed ships was £98,179.

The average cost of the contract sheathed ships was £106,947, or £96,947 exclusive of sheathing, and that of the unsheathed ships was £97,130.

The excess in the cost of the two Dockyard sheathed ships is doubtless attributable in large measure to one of them having been laid down at Devonport and one at Sheerness at a time when each of those yards was imperfectly adapted for much of this class of work. The deficiencies were remedied as soon as possible, and the cost of work became much reduced. No vessel of anything like the dimensions of this class had been attempted before at Sheerness. The cost of these two ships does not represent what should now be required at any of the Dockyards.

If we strike these two vessels out of the comparison, however, we are left with the two unsheathed ships built at Chatham, which still cost more, exclusive of incidental charges, than the average of the contract unsheathed ships, or that of the contract sheathed ships, exclusive of sheathing. There may be something in the fact that these were the pioneer ships of the class, and all the details of construction and of arrangements and fittings had to be worked out in them for all the ships; but after making every allowance, it does not appear that such ships are being built in the Dockyards for much less, exclusive of incidental charges, than they can be procured by contract.

Third-class Cruisers.

The difference between the average cost of the hull, fittings, and equipment for the Dockyard ships and that of the contract ships of this class is very great. The average for the Dockyard ships is £77,280, exclusive of incidental charges, and that for the contract ships is £64,234, or £13,046 less. It has always been understood, however, that there was a heavy loss upon the hulls of the contract ships of this class. On the other hand, two of the Dockyard ships were built under unfavourable conditions at Devonport, and one, which proved to be the most costly of all, at Pembroke. The one

built at Portsmouth cost £73,450, or £9,216 more than the average of the contract ships, and such a vessel should certainly be built now for at least that amount at any of the yards. It must be remembered also that three ships were given out under one contract and two under another, and that building three ships or two ships together would reduce the average cost.

Torpedo Gunboats.

The average cost of hull, fittings, and equipment for the Dockyard boats is £28,257, and for the contract boats is £25,663. The Dockyard boats were, however, much delayed in their progress pending the discussion and settlement of various modifications that were found desirable. This caused the *Antelope*, built at Devonport, and the *Circe* and *Hebe*, built at Sheerness, to be stopped for a long time during the early period of their construction. The other two Dockyard boats, the *Alarm* and *Leda*, which were not laid down till a year and a half later, when all doubtful points had been decided, and the contract boats were being ordered, cost £26,893 and £26,414 respectively. This is an average of £991 more than the contract boats.

Comparative Cost of Dockyard Work.

It would appear, taking into consideration the estimates for the battleships of the *Magnificent* class, as well as the costs of the *Royal Sovereign* class, that the hulls of first-class battleships should now be built, fitted, and equipped in the Dockyards for about 10 per cent. less, exclusive of incidental charges, than they could be procured by contract, reckoning this percentage upon the total cost of hull, fittings, and equipment, without vertical armour. Also that the largest type of protected cruisers should be built in the Dockyards for 5 to, perhaps, 10 per cent. less than by contract; and that small cruisers and gunboats are costing about the same whether built in the Dockyards or by contract. This opinion is based upon my own experience of the cost of work in the Dockyards during recent years, as well as upon the actual cost results of the Naval Defence ships—the latter requiring to be judged with reference to important changes made in the Dockyards since some of those ships were commenced, that should enable the costs to be reduced.

It is difficult to see why the relative costs of Dockyard ships and contract ships should vary with the size of ship, and it is probable that this difference is only temporary and will disappear. It has already become much less than it was, owing to the economical progress being made all round in the Dockyards, as will be shown further on. Given a condition of things under which each Dockyard would receive regular supplies of work, as is now practically the case, and each class of ship would have the same skilled supervision and attention, and the same advantage in the use of machines and labour-saving

appliances, which ought now to be practicable, and under which also a sufficient number of ships would be built by contract, to give private shipbuilders the experience requisite for reducing the cost of work, and estimating accurately the cost of, and the profit upon, a contract; there could then be no reason why the difference of cost should be greater for one class of vessel than for another.

The comparative excess of cost of some of the Dockyard ships dealt with in this paper, and the extent to which such excess may fairly be attributable to temporary causes, cannot be properly judged of without a knowledge of many circumstances not disclosed in the Parliamentary Papers. The fact is, there has been a great and rapid reduction during the past nine years in the cost of building ships of all classes in the Dockyards, and one of the chief points brought out by the differences of relative cost in the various ships now under consideration is that, the reduction was made faster at first in some than in others. The differences between the cost of work in the various Dockyards show, to some extent, the effect of inadequate appliances or arrangements for carrying on work quickly and economically. The most costly ships are those built at yards which were the most backward at first in these respects; and much might yet be done in the way of improvement.

It was between nine and ten years ago that the Admiralty took up the question seriously of the cost of work, and the time it took to build ships, in the Dockyards. Public attention and criticism were then persistently directed to these matters, especially with reference to battleships. The efforts made to effect improvements were naturally commenced with the largest and most important ships, that had been the chief objects of criticism. During the period of change it will be found, therefore, that the progress of improvement was more rapid in connection with battleships than with the smaller classes of vessels.

The progress made during the period mentioned can be judged roughly by the particulars given in Appendix C of the cost of labour per ton weight of hull, fittings, and equipment, exclusive of armour and protective deck plating, of ships built in the Dockyards during the last twenty years. Owing to the system upon which the cost accounts were formerly kept, as explained in the early part of this paper, it has never been possible to analyse or compare the costs in detail; and it has even been very difficult to extract information from the accounts that would enable the costs of ships built at different times to be compared upon the same basis. The best standard of comparison, that the old cost accounts admit of, is the cost per ton of the labour employed in the construction, fitting, and equipment of the hull, after deducting from the weight of hull and from its total cost the weight and the cost of the armour, and the cost of fitting the armour to the ship. The particulars in Appendix C show that the average cost of labour per ton weight of hull of the armoured ships, exclusive of

armour, built during the period 1876-86 was £50 14s. 8d.; of those built during the period 1881-89, £46 11s. 6d.; and of those commenced after 1885, £35 14s. 8d. The average cost of labour per ton weight of hull of the unarmoured ships built during the period 1875-86 was £46 8s.; of those built during the period 1883-91, £40 3s.; and of those commenced after 1886, £34 8s. 6d. The costs of the ships commenced prior to 1886, but not completed till after that year, benefited, of course, by the operation of the same causes that led to the general reduction of cost upon ships that were commenced during and after the year 1886.

Although this is only a rough comparison, owing to the cost of fittings, and equipment, as well as that of the structure of the hull being taken in proportion to the total weight, it is sufficient to show that a great reduction was effected in the rate of expenditure upon labour, both in armoured and unarmoured ships. Such a comparison, while showing generally the amount of the reduction, would not be accurate as between ships of different type. It would be much more interesting and instructive if the cost of the structure could be separated from that of the fittings and equipment, but that is only possible for ships whose costs have been kept under the present system of estimates and accounts, which was introduced in 1887. Hull, fittings, and equipment have all to be taken together in the older ships, and the present comparison between old and new ships can only be made on that basis. This tells against the modern ships in any such comparison as the present, because fittings have been continuously increasing in number and complexity, and their cost has been going up much more rapidly than the additional weight they involve.

The recent reductions in the direct charges for labour employed upon shipbuilding has been attended by a great decrease in those items of incidental expenditure at the Dockyards that could be controlled by the officers; and certain items formerly included in incidental expenditure have been charged direct to ships since 1888, and are included in the costs made up since that time.

There are many reasons why ships are now built cheaper in the Dockyards than during the first ten years of the period to which the statement in Appendix C relates, viz., from 1876 to 1886. The chief is, perhaps, that instead of the uncertainty and the constant changes that attended the construction of the principal ships built in the Dockyards during the ten years referred to, the Board of Admiralty has since decided absolutely upon the design and specifications of ships before they were laid down; and the original designs have been strictly carried out, with few and comparatively unimportant exceptions. During the period prior to 1886 great changes were made in the nature of the armour and in the armaments of ships. The principal vessels were laid down before their armaments were decided; and the progress of work was constantly being delayed pending the results of important experiments, or being interfered with by radical alterations of arrangements. It was impossible to build

ships cheaply or quickly under such conditions, or to estimate what they were likely to cost.

This state of matters continued so long that, the workmen and officers in the Dockyards appeared to lose much of the energy and enthusiasm requisite for the economical and rapid carrying out of shipbuilding work. Many of the earlier traditions of rapid construction were either forgotten or were thought to have become obsolete. When the *Trafalgar* and *Nile* were laid down in the beginning of 1886 it was considered in the Dockyards impossible to complete a first-class battleship in less than five years; whereas such ships are now built in less than three years. The approved estimate for labour on the hull of the *Trafalgar* was £265,000; and this was based on the assumption that there would be no delays as in former ships for decisions with reference to armament and torpedo fittings or other matters, and no expensive alterations. The cost of the labour amounted to £183,593 when the ship was complete; and that included all alterations and additions made during the progress of the work. The estimate for labour on each of the hulls of the ships of the *Royal Sovereign* class was based upon the cost results of the *Trafalgar*, then nearly complete, and amounted to £212,000. The actual cost, which again included all alterations and additions made during the progress of the work, was an average of £200,682 for the four ships, and £186,587 for the *Royal Sovereign* herself.

The shipbuilding work in the Dockyards has gone on for several years in a straightforward manner. The results are now public, and the dissatisfaction that once prevailed in the country with regard to it has ceased to exist. Since the Dockyards have had a fair chance of showing what they can do, they have at least justified their employment upon the work of building new ships. The country is well served both by the officers and men in the Dockyards; and these are animated all round by an excellent spirit, and a desire to show the best possible results in comparison with private shipbuilders. Under the present system we find that estimates of the cost of work are trustworthy, the details of cost are accurately kept, and are of real practical use in checking departmental expenditure. There is active and intelligent supervision and control of work; and the stimulus is everywhere felt of active competition in economy and despatch of work among the various officers and the several Dockyards. These conditions ensure a continuance of progress, and of public confidence in our great national Dockyards.

Reference is often made to the enormous cost of modern battleships. Each ship of the *Royal Sovereign* and *Magnificent* classes costs, with incidental charges, £850,000 to £900,000, without armament, ammunition, or sea-stores. A little over two-thirds of this amount is expended upon the hull, fittings, and equipment. The most important item of cost is, however, the armour plating; and it is a peculiarity of this item, that while the cost of hull, apart from armour, and the cost also of propelling machinery have been greatly reduced during recent years, the cost of armour has been increasing.

Modern mechanical improvements, that have so much diminished the cost of production in other departments, have failed to prevent the market price of armour plates from increasing. The armour of the present day is twice as costly as the iron armour of twenty to thirty years ago. The result is that we have reached a point at which the vertical armour upon a ship costs double that of all the other materials of the hull, including the whole of the fittings and equipment, as in the *Royal Sovereign* class; and where it amounts to nearly half the total cost, for materials and labour, of the hull, fittings, and equipment, as in the *Magnificent* class.

Incidental Charges.

It would be impossible, within the limits of such a paper as this, to discuss fully the difficult and complicated question of Dockyard incidental charges. These constitute an important item in the returns of cost; and the subject cannot, therefore, be entirely avoided. All that is practicable now, however, is to offer a few general remarks upon the difference between Dockyard incidental charges and the establishment charges of a private shipbuilder or engineer.

The works of a private shipbuilder or engineer exist only for the construction or repairs of ships and machinery. The whole of the expenditure arises out of the requirements of such work, whether it can be charged direct as it is incurred to specific ships, or other items, or not. A private shipbuilder completes the vessels he contracts to build, and immediately delivers them to their owner, who takes them away; or he receives a vessel from her owners for repair, and gets rid of her as soon as the repairs are complete. The cost of the labour and materials employed upon each job is brought readily to account, and all the remaining expenditure, such as that upon rent, offices, salaries, &c., has clearly been due to the work that has been performed, and that only, and it is therefore usual to distribute this over the various items *pro rata* to the amounts of the direct charges for labour and materials, or for labour alone.

In the Dockyards the conditions are very different. A Dockyard is an enormous establishment of a composite character, in which shipbuilding and the repairs of ships are combined with what would be, in the Mercantile Marine, the business of a shipowner and dock company, involving as it does everything relating to the equipment, the storing, and the care and preservation, of all the ships of H.M. Navy. After these have been built or repaired, in the Dockyards or by contract, they have to be accommodated and maintained as long as required in reserve, or while they are being stored, armed, and equipped for sea; and the same between their various voyages or commissions.

The Dockyards have grown greatly in size, to a size far beyond normal requirements, even for all the purposes named—in order that the country might possess the means of dealing quickly with a large number of ships in time of pressure, or of panic; and of

repairing, equipping, and storing fleets with rapidity, during war time, or after a naval engagement.

Increase of size in establishments of this kind necessitates of itself extra cost of management and supervision, and general increase of incidental expenditure. Hence, one of the most difficult questions in connection with the total cost of shipbuilding work in the Dockyards—a question that has never yet been exhaustively dealt with—is what proportion of the various items of incidental expenditure is fairly chargeable to the building and repair of ships.

The details of the incidental expenditure at the various Dockyards, and the proportions of the various items that are charged to shipbuilding work, are given in the Dockyard Expense Accounts for each year, and can be examined by any who are interested in the subject. It is there shown how the percentages of the direct charges are arrived at which give the amounts shown in the present tables for incidental charges against each ship. Seeing that the stoppage of all shipbuilding in the Dockyards would make but little difference in the Incidental Expenditure, so long as they are made to fulfil with efficiency all the other purposes for which they exist, it is an important question how much of that expenditure should fairly be charged against shipbuilding.

Conclusion.

Almost every subject relating to the design and construction of warships has been frequently discussed in this Institution, except that of cost. The cost of building the ships of the Navy is, however, a subject of great professional, as well as national, interest and importance; and, as such, it is surely worthy the attention of members of the Institution. The efforts made to reduce expenditure upon shipbuilding and to promote economy in our Dockyards have not always been admired. It has sometimes been assumed that reduction of cost must necessarily involve the sacrifice of something worth having, or a degradation of the quality of the work. The common way of expressing this is that cheap work means bad work. While it is true, of course, that money can be saved by scamping work, it is equally true that expensive work in shipbuilding is not always the best. The best managed shipyards I know are those in which the work is not only of the best quality, but is the least expensive. A careful attention to economy of work, and to the conditions upon which it depends, has done much during recent years at the Admiralty and in the Dockyards, as I trust the facts stated in this paper show, to reduce the cost, and the time required for the building, of warships, without any sacrifice of quality or efficiency. The more the matter is looked into and discussed by shipbuilders for the Navy, in the Dockyards and in private establishments, the more progress will be made in future in the same direction; and the better it will be for Her Majesty's Navy and for the country which relies upon it for its chief defence.

APPENDIX I.

Statement appended to the Report of the Comptroller and Auditor-General upon the accounts prepared at the Admiralty under the Provisions of the Naval Defence Acts, 1889 and 1893.

Comparison of Cost of Completed Vessels Built by Contract and in Her Majesty's Dockyards respectively.

CONTRACT.		DOCKYARD.		
Name of Ship.	Total Cost as shown in Appendix to Expense Accounts, 1893—94.	Name of Ship.	Places where Built.	Total Cost as shown in Appendix to Expense Accounts, 1893—94.
First-Class Battleships.				
Ramillies	£899,321	Hood	Chatham	£846,299
Resolution	870,703	Empress of India ...	Pembroke	844,124
Revenge*		Royal Sovereign ...	Portsmouth	837,148
First-Class Cruisers.				
Endymion	362,637	Royal Arthur	Portsmouth	406,224
Gibraltar	361,166	Crescent	Chatham	387,827
Grafton	361,255	Edgar	Devonport	408,198
		Hawke	Chatham	396,265
Second-Class Cruisers.				
Indefatigable	182,863	Andromache	Chatham	189,329
Intrepid	183,284	Æolus	Devonport	212,383
Iphigenia	184,997	Apollo	Chatham	190,214
Latona...	173,251	Bonaventure	Devonport	247,373
Melampus	174,402	Brilliant	Sheerness	216,557
Naïad	173,997			
Pique	187,693			
Rainbow	187,019			
Retribution	187,846			
Sappho	175,988			
Scylla	175,751			
Sirius	190,276			
Spartan	189,068			
Terpsichore	175,908			
Thetis	175,171			
Tribune	174,977			
Torpedo Gunboats.				
Jaseur	50,184	Alarm	Sheerness	62,397
Jason	50,127	Circe	Ditto	65,568
Niger	49,801	Gleaner	Ditto	66.327
Onyx	56,019	Gossamer	Ditto	63,344
Renard	55,958	Hebe	Ditto	73,799
Speedy...	61,383	Leda	Ditto	62,639

Note.—The cost of contract ships includes an approximate levy for Admiralty incidental charges on building, in order to render the comparison more complete.

* H.M.S. *Revenge* was passed into the Fleet Reserve in March, 1894, but the record of expenditure was not quite complete in 1893-94.

APPENDIX II.

List of the Principal Heads of the Estimates and the Cost Accounts Prepared in H.M. Dockyards for the Building of Iron, Steel, Sheathed, and Composite Ships.

A. Forgings and castings.
B. Structural iron and steel.
C. Armour.
D. Draughtsmen.
E. Smiths' work.
F. Shipwrights', shipfitters', and wood caulkers' work.
G. Joiners' work.
H. Painters' work.
I. Plumbers' work.
K. Other trades.
L. Miscellaneous work (this includes launching, shoring, staging, docking, moving ship from place to place, &c.).
M. General labour, cartage, &c.
N. Sundries (this includes coal, gas, candles, temporary electric lighting, tools, &c.).
O. Armament fittings.
P. Torpedo equipment.
Q. Electric lighting.
R. Pumping and draining arrangements (including fire service).
S. Ventilation.
T. Watertight doors.
U. Steering gear.
V. Anchor and cable arrangements.
W. Masts, yards, derricks, rigging, blocks, and sails and awnings not supplied under establishment.
X. Machinery (this is for the shipyard expenditure in connection with machinery, not the cost of the machinery itself).
Z. General expenditure.*

* In the manufacturing shops, such as saw-mills, foundries, &c., there is an expenditure of materials and labour that cannot be charged direct to ships or to the separate articles dealt with or manufactured, such as that incurred upon the repair and replacement of tools, working and repairing machines, &c.; and this expenditure is distributed periodically over (*a*) ships and other services, and (*b*) articles dealt with or manufactured. The amount charged against any particular ship is calculated upon the estimated labour to be expended in the shops at the ascertained average rates for labour and materials for each shop.

APPENDIX III.

Statement of Cost per Ton weight of Hull, Fittings, and Equipment, exclusive of Armour and Protective Deck Plating, of the labour employed in the construction of the undermentioned Ships built in H.M. Dockyards.

BATTLESHIPS.						CRUISERS.					
Name of Ship.	Period of Construction.	Cost per ton.				Name of Ship.	Period of Construction.	Cost per ton.			
		£	s.	d.				£	s.	d.	
Ajax	1876–85	46	10	0		Iris	1875–79	44	4	0	
Agamemnon	1876–85	46	4	0		Mercury	1876–83	50	0	0	
Edinburgh	1879–87	53	18	0		Canada*	1879–83	44	0	0	
Colossus	1879–86	57	8	0		Cordelia*	1879–84	42	18	0	
Conqueror	1879–86	48	14	0		Calypso*	1881–85	44	10	0	
Impérieuse*	1881–86	51	14	0		Calliope*	1881–86	40	0	0	
Warspite*	1881–88	48	0	0		Mersey	1883–87	41	18	0	
Collingwood	1880–87	49	14	0		Severn...	1884–88	38	18	0	
Rodney	1882–88	50	14	0		Thames	1884–91	40	4	0	
Howe	1882–88	44	12	0		Forth	1884–91	39	12	0	
Camperdown	1882–89	45	16	0		Medea	1887–90	31	8	0	
Anson	1883–89	42	16	0		Medusa	1887–90	31	10	0	
Hero	1884–88	44	8	0		Melpomene*	1888–90	31	8	0	
Trafalgar	1886–90	36	6	0		Blanche*	1888–91	38	10	0	
Nile	1886–91	38	18	0		Blonde*	1888–91	37	14	0	
Royal Sovereign ...	1889–92	32	0	0		Barrosa*	1888–91	34	12	0	
						Barracouta*	1888–91	36	4	0	
						Barham	1888–91	34	18	0	
						Pallas	1888–91	33	2	0	
						Royal Arthur* ...	1890–93	36	14	0	
						Crescent*	1890–93	33	4	0	

* The bottoms of these ships are sheathed with copper and wood

DISCUSSION.

Mr. W. H. Jaques, late U.S.N. (Associate): Lord Brassey, Ladies and Gentlemen, although Dr. Elgar's very interesting paper treats more directly of the comparative cost of warships built in British Dockyards and by contract, there are a few points to which I ask a few moments' consideration. Near the bottom of page 96 he refers to the delays, and consequent increase of cost, "pending the result of important experiments, or being interfered with by radical alterations of arrangements." Not only do these greatly increase the cost of production, but they seriously impair the efficiency of the ship. Better construct rapidly on original design, and build more ships, than attempt to incorporate, under delayed construction, those elements which make her neither one thing nor the other. At the bottom of page 97 Dr. Elgar refers to the increasing cost of armour. I assume he refers to Great Britain, because in the United States it is decreasing. As we are the guests of the nation that has done so much for this important factor in warfare, both on land and sea, I may be permitted to give this point more than a passing reference; and as homogeneous steel armour has so radically displaced other types, I am sure you will all join me in a tribute to Mr. Henri Schneider, its leading exponent. Not only did he produce plain steel plates that showed themselves superior to others, but it was he who first discovered to us the great advantages of nickel in steel, and who made the first heavy nickel-steel armour plate—the test of which so splendidly endorsed his opinions. Taking into consideration the enormous increase of weight of iron required for equal protection, the modern gas-supercarbonised nickel steel armour will in actual figures cost no more; but in tho advantage of protecting a greater surface with less weight will render the armour costs-sheet less. In fact, speaking of the Harveyed homogeneous steel plates adopted by Great Britain, a recent Admiralty report stated:—"In the course of the experiments the use of nickel as an alloy of steel for the purposes of armour plates has been fully tested. It has been established that Harveyed plates, without nickel in the steel, show resistance to modern projectiles as great as any hitherto obtained when nickel was combined with steel in plates also treated by the Harvey process. The consequence of adopting this new system will be a great saving in cost for a given defence." Nickel steel is making such rapid strides towards universal adoption that a word will be most appropriate in connection with its bearing upon the cost of warships. Already in the United States it has been largely employed for armour, guns, shafting, hammer and piston rods, torpedoes, wire, and has been ordered for ship and boiler plates. Even the thousands of bicycles that are reducing the incomes of our railroads and the value of our horses, are made of steel tubing containing a small percentage of this valuable metal—nickel. Sir William White, in his paper "On Wood and Copper Sheathing for Steel Ships," read on Tuesday last, stated that, after "thorough investigation at the Admiralty into the relative advantages and disadvantages of substituting a non-corrodible skin for the combination of steel and wood usually adopted in sheathed ships, the conclusion reached was that it was preferable on the grounds of cost and efficiency to adhere to the use of wood and copper sheathing"; and, in referring to nickel, said, "When nickel steel, with high percentages of nickel and relatively incorrodible, was introduced, the matter was again considered, but no change was thought desirable." While copper contains elements that are considered more antagonistic to fouling growth than any other metal yet employed, the non-corrodible quality of nickel, and the smooth surface that can be obtained with it, have influenced the United States Navy Department to seriously consider its use for one of the gunboats about to be laid down. In fact, from the cost alone I think I can safely say that, in the near future, we will have afloat nickel-steel ships, protected by nickel-steel armour, armed with nickel-

steel guns, and nickel-steel shafting, driven by power generated in nickel-steel boilers. With less corrodible boilers, admitting an increase of pressure—an economy in itself; with hulls requiring no increased weight and cost of sheathing; with armour protection permitting a reduction of 25 per cent. in thickness, the increased efficiency will be so marked that, even at the present price of nickel, its general employment cannot much longer be deferred. Using Dr. Elgar's figures on page 78, and his estimate of the thickness of armour of the first-class battleships as 18 in., there would be a saving of £64,000 alone in the item of armour. Further, the general use of nickel in steel will quickly reduce its cost. While we are all greatly indebted to Dr. Elgar for his very instructive paper, I have to thank you and him for this opportunity to express the hope, personally, as a member of the Council of the American Society of Naval Architects, that one of the next Summer Meetings of our Institution may take place in the United States.

Sir Nathaniel Barnaby, K.C.B. (Vice-President): My Lord, Ladies and Gentlemen, I had not intended to speak upon this paper. I had hoped that our French friends present would have been ready to speak at once, because I know how very interesting to them this paper must be. While an attempt is being made to overcome their modesty, and to induce them to speak to us, I will just say a few words on a subject which interests me deeply, because a good many of the ships which appear here to be very costly are ships which were built during the time when I was in office at the Admiralty —not directly responsible for the cost of the ships, as Dr. Elgar was, but very much interested indeed in the question of the administration of Dockyards and the cost of the ships. I cannot complain of the tone of the paper which has been read by Professor Elgar; it is not only a valuable paper, but it is a paper which has been prepared with much consideration for the feelings of those whose work he has been obliged to criticise. I would only like to say one thing which may escape attention, and that is that, during the time when some of the ships were building which appear to be very costly, we, in England, had the misfortune to have to make an entire change in the construction of our guns. In France you were wise enough to continue the system of breech-loading guns. In England we were so foolish that we departed from breech-loading guns, built muzzle-loading guns, continued to build muzzle-loading guns long after it was seen that we must in the end take to your system, and have breech-loading guns. During those years the changes in the character of the gun itself, the changes in the mountings, the changes required in the decks and fittings of all kinds, led to untold trouble and expense. The delays were enormous—the spirit of the Dockyards was completely broken by the fact that they would prepare or fit a ship for a particular gun and a particular carriage, and, shortly after that was completed, we were obliged, the new guns being ready for us, to change it all, and put the new system of guns into the ship. I think it is necessary to say that, in order to explain to the French gentlemen here what must otherwise be somewhat difficult to understand. It may seem to some of you that it is not a very important thing whether a gun should be a muzzle-loading or a breech-loading gun in the question of the cost of the construction of the ship, but my French colleagues know how important that consideration is. Take, for example, this:—The gunners built for us guns of 81 tons, 40 ft. long. They said to us, "You must load those guns at the muzzle"—a large order—an order which, as we now see, ought never to have been given. The guns ought to have been loaded at the breech. I do not say that by way of complaint. In England everyone was trying to do what was best for the country, as you do in France; but we went wrong, we have had to pay for it, and Professor Elgar's statements here—particularly those on the last page of all, 102—can only be understood, in such a company as this, by some such words in explanation as those which I have had the honour to address to you.

Mr. A. E. Seaton (Member of Council): My Lord, Ladies and Gentlemen, I think the Institution is very much indebted to Professor Elgar for giving us this paper, inasmuch as it is, I believe, the first attempt to introduce the question of cost into our calculations. We, as producers, as manufacturers, have always that before us as perhaps our most serious item of contemplation; in fact, the equilibrium of our scientific mind is often upset by the considerations of cost, and if we do not always what we would, it is because our tether is often limited. There is one thing absent from this paper to-day, which I regret very much. It is due to the innate and well-known modesty of our friend Professor Elgar, and that is, he has not told us (I do not blame him for it, I admire him rather than that) that much of the reform effected in the Dockyards is due to the very able way in which he administered the office he had the honour of occupying at the time. Twenty years ago I had the pleasure as well as the honour of serving under Dr. Elgar, so I know his ability, not only as a scientific shipbuilder, but as a good practical commercial man; and when he was appointed to the administration of the Dockyards, I, as a taxpayer and British citizen, felt sure they had put the right man in the right place. I think the evidence of that is shown in the able way in which he has dissected the figures given in this paper. There are one or two points, however, which I do not think have escaped him, but perhaps he has conveniently shut his eyes to them. One is that in the Royal Dockyards they have a discipline, and a means of maintaining discipline, that we unfortunately do not possess in private firms; not only have they control of the men when at work, but the avoidance of what is generally known now under the head of labour troubles. It is very true that the disease in a sporadic form has appeared in the Dockyards, but it has been so mild that I think M. Pasteur must have inoculated them before they took the disease, because the troubles that our friends at the Admiralty have to meet in that direction are mere bagatelles compared with what we have had to face in the private yards. I speak to-day with a considerable amount of reserve on Admiralty work, inasmuch as my firm is one of the three which at the present time have the disagreeable duty forced upon them of seeking redress by arbitration. Dr. Elgar has shown you a comparison of the figures of cost, taken from the Blue Books, of the private-built ships and the Dockyard-built ships; but, had he had access to some other books of a bulkier form, which are not printed, I think his figures would have been very different to-day. They would have shown that the cost, we will say, of the battleships as built by the private firms would compare very favourably with that of those built in the Dockyards. I believe it is an open secret that those firms who were fortunate enough to secure the orders for the battleships did very well out of them. They had a great advantage, and it was this: that to a certain extent for honour and glory, but, as shown by Dr. Elgar to-day, really for economy, the *Royal Sovereign* herself was pushed forward very rapidly—so rapidly, in fact, that it enabled those builders who had the construction of the sister ships to keep draughtsmen in constant employ on the ship making notes of everything that was being done, and the consequence was that at the private yards they knew well beforehand exactly the kind of fittings that was required, and what would pass muster; also they learnt the best way of manufacturing them. On the contrary, with the first-class cruisers we got ahead of the Dockyards, and not only ahead of the Dockyards, but ahead of the drawing staff of the Admiralty, with the result that we were in that state that existed at the Dockyard before our friend here administered it—that is, to use an expression which is well known to you, we did not know where we were. The result was that work had to stand still. Sometimes, if we were venturesome enough, or our overseer thought he knew enough, to let us go ahead, we were in the unfortunate position of having to pull down and to do the work over again. I can thoroughly understand the position of the Dockyards before the system Dr. Elgar has spoken of, by our own experience with first-class cruisers. I do not want to dwell on that too much,

because, as I say, it is to some extent *sub judice*. There is one advantage the Dockyards have over us, too—that is, the supervision is of a kindly nature. If some of us were appointed overseers at the Dockyards, I do not know how the expense account might be affected. You will remember that the gentlemen who oversee us are Dockyard authorities themselves, whose sympathies must necessarily be with the Dockyards. We have been during the past five or six years spurred on, or, you might almost say, irritated into an activity which is most undesirable, and that irritation has shown itself in making our work as expensive as possible. Then, again, the Naval Defence Act of 1889 was such a gigantic affair, that the whole of the manufacturers of Great Britain were, more or less, taking part in the production either of the raw material or of the partly finished material. The gentlemen who have the passing of that are also themselves, of course, Government officers, and all of them, I believe, from the Dockyard. We, therefore, used to find considerable difficulty in getting our material passed and delivered. We found that, naturally, preference was given to the Dockyard. So that, although I think the country, and the servants of the country who have done that work—and at their head Professor Elgar—ought to be congratulated on the great reform that has been effected in naval shipbuilding; still it has to some extent been at the expense of those private firms who have had to build the ships, and to have comparisons made, such as have been made to-day. In Professor Elgar we have a kindly and friendly, as well as an impartial critic, therefore I do not make these remarks in any sense of complaint; on the contrary, I think he has dealt in this paper most fairly by us. He has spoken a little strongly of the results of the building of the first-class cruisers, but if there are any builders of second-class cruisers here—and I believe there are—they can, I believe, bear me out when I say that, their losses were, in proportion, as great as ours. They did not make their complaints quite so pronounced, but I believe there was a strong rumbling as of earthquakes when it came out that the first-class cruiser people were claiming to have their matters reconsidered. Without detaining the meeting any longer, I should say that papers of this kind, not only as reviews of the Naval Defence Act, but of all matters of the cost of engineering and shipbuilding, might be well considered by the Institution. I think our best efforts are the result of our desire to work economically. I think the best test of a good shipbuilder and engineer is how well he can do his work on the least cost. I know that if a well-equipped establishment like a Dockyard were placed in the hands of an ordinary shipbuilder, he ought to be able to work economically; but that we can, with our limited appliances and limited capital and somewhat limited staff, compete with the Dockyards, is not only our pride, but the real test of our position as shipbuilders and engineers.

Monsieur Bienaymé, Inspecteur-Général des Constructions Navales, Paris (Visitor): I have listened with the greatest interest to this remarkable communication of Professor Elgar, which contains so much valuable information. In France the cost of warships, whether constructed in public or private dockyards, is very much the same; in no case does one see in France the wide differences which have been brought to notice by Mr. Elgar. These differences struck me about two years ago, when I occupied the position of Directeur du Matériel at the French Ministry of Marine, and when I was led, for my own instruction, to compare the figures of cost inserted in the Naval Estimates for the years 1893-1894, and to estimate the differences, which, when compared with those existing for French ships, appeared to me to be inexplicable. Mr. Elgar has given very clearly the reasons for these facts, from which we may conclude that the equality in cost which has been proved to exist in the case of French ships, whether constructed in the public dockyards, or by private industry, arises from the fact that the plant and machinery, or, in a word, the conditions of work, are the same in both cases. I regret very much to say that the conditions of work which exist in the French yards are not very brilliant

when compared with those which obtain in England, and that, both State and private industry should model themselves on our English friends, and should, in order to attain cheapness and rapidity of work, undergo the sacrifices which the latter impose on themselves with so much intelligence, as soon as the necessity for them has been proved to exist. I thank Professor Elgar most heartily for his paper.

Mr. B. Martell (Vice-President): My Lord and Gentlemen, I should not trouble you with any remarks on this most valuable paper, were it not for the last paragraph on page 99. Some time after Dr. Elgar was appointed Director of Her Majesty's Dockyards it became known that there was a great saving in the cost of the construction of Her Majesty's ships, and an opinion got abroad that the saving effected in this way was mainly due to the inferior workmanship—that they did more work, but that the work was not so carefully done in Her Majesty's Dockyards as used to be the case. The late Admiral Kelly, who was at that time Superintendent of Chatham Dockyard, was a very earnest man, and he became very anxious on this subject, because some remarks got into the public journals to the effect that, it was thought that the saving was greatly due to the scamping, if I may say so, of the work, by doing a greater quantity at the same cost. He therefore requested me particularly to join him at Chatham and accompany him over the ships in course of construction there, in order that I might give him an independent opinion as to whether there was any truth in these remarks. I went to Chatham, and I went over all the ships in course of construction at that time, and I was very happy indeed to be able to tell him that there was no ground whatever for such a remark as that. The workmanship that I saw being carried on in those ships—throughout the whole of the ships in course of construction—was of the very best character, and knowing, as I did, what the workmanship in Her Majesty's Dockyards had been, and ought to be, I could safely assure him that there had been no deterioration whatever in the manner of constructing those ships, and therefore, that the economy and saving which had been shown was doubtless due to the system which had been inaugurated by the Director of Her Majesty's Dockyards.

The President (the Right Hon. Lord Brassey, K.C.B.): Gentlemen—and I am happy to be able to say Ladies also, although I should put them first—Ladies and Gentlemen. It is my pleasure on your behalf to return our most grateful thanks to Dr. Elgar for his valuable paper. It is really an extensive examination of a most important practical question, and for this collection of statistics—a collection such as has never been brought together before—I say the administrations of all countries, and especially our administration in England, are greatly indebted to Dr. Elgar. As you know, I was for some years in a position of some responsibility at our own Admiralty, and in that position it was my duty to give very great consideration to the relative cost of construction in the Dockyards and in the private yards. We had to give our attention to that subject; but there was no such collection of information by which to form a judgment as that which has now been supplied to us in this paper by Dr. Elgar. One had to form a sort of rough impression of the relative cost of construction in the Dockyards and in the private yards, and at the time of which I speak—now some years ago—I had an impression, roughly formed, that the Dockyard building cost about 10 per cent. more than similar construction in the private yards. Now, it would appear from the figures which Dr. Elgar has placed before us, that, by an improved administration—a steadily improving administration in the Dockyards, an improvement which began under Sir Nathaniel Barnaby, and has been followed by his successors, and is still going forward—we have brought the cost of construction approximately to a level, in the Dockyards and in the private yards. I do say that that is a marvellous result, when you take into view the widely different conditions under which work is carried on in the private yards and in the public

yards. Of course, when I say that we have brought that cost approximately to a level, that does not appear absolutely on the figures as placed before us by Professor Elgar ; but then you have to make some corrections when you form your judgment upon those figures. You certainly ought to add to the cost, as shown by Professor Elgar, of the contract-built ships, the very considerable sums which have been lost, at any rate, on many of the contracts undertaken by private shipbuilders; and, if you deal fairly with the Dockyards, you must make considerable reductions for the expenses which are necessarily incurred in public establishments as compared with private establishments, and if you make that addition to the cost of the contract-built ships, and the deduction from the cost of Dockyard-built ships, you really arrive approximately at a level. Now, if that is the case, it is quite clear what the policy should be of any great public administration. If there exist in any country large resources for construction by private enterprise, it is evident that it is policy to make use of those resources. After all, those who administer a great navy are not only naval men, but they must be men in a large and high sense politicians—they must be statesmen; and if there exists a large body of capable workmen employed in the private yards of the country, and they see that a large public expenditure is taking place, they will naturally claim that some part of that expenditure shall go to the private firms. You cannot resist that demand—you must comply with it. Then, further, there is this consideration, that if you want the resources of the country to be as elastic as possible —if you want to be in a condition to meet in the most effective manner a demand suddenly growing up in a great national emergency, it is clear you ought not only to have your public establishments, but as many private establishments as possible, equipped with the necessary knowledge and experience to meet the demand, and to give service to the State. If that is so, it is quite clear you should, as fairly as possible, divide the orders between the public and the private yards. That is what is being done in England, and that is what is being done in France, and I think both countries should be congratulated that they have not only their great public yards, but those important private establishments which really are a pride and resource to both countries. For the information which Professor Elgar has given us, in a manner in which it has never been given before, he deserves the best thanks of the Institution, and those I beg to convey to him.

Mr. F. Elgar, LL.D., F.R.S.E. (Vice-President): My Lord, I do not find that anything appears to be called for in the nature of a reply. I might add, with reference to Sir Nathaniel Barnaby's explanation of the difficulties under which he and my predecessor at the Admiralty, Mr. Barnes, had to work for many years, that his description of those difficulties agrees with the opinion I formed several years ago, after reading the official history of the design and construction of the ships which is preserved in the Admiralty records. But I should have been inclined to put this more strongly even than Sir Nathaniel Barnaby does. The only feeling that anyone could have, who has had the opportunity of reading the official papers on the subject, is one of wonder that the Admiralty constructors ever succeeded in getting a ship completed at all in the Dockyards under such conditions. With regard to the remarks of Captain Jaques upon the cost of armour plating, I would explain that what I have said upon the subject is with reference to the great increase of cost during the last twenty to thirty years—since a time long prior to the establishment of armour-plate manufacture in America. The changes that have taken place in the price of armour plates in America during the comparatively short time they have been manufactured in that country do not, of course, affect the statement in the paper. I will not now say any more, as I have to remember there are two gentlemen to follow me in the reading of papers, and time is passing rapidly. I would only thank the President, and the other gentlemen who have spoken, for the generous terms in which they have referred to the paper.

ON WATER-TUBE BOILERS.

By Monsieur J. A. Normand, Member.

[Read at the Summer Meeting of the Thirty-sixth Session of the Institution of Naval Architects, June 13, 1895; the Right Hon. Lord Brassey, K.C.B., President, in the Chair.]

Water-tube boilers are inferior to the ordinary marine type in this, that any damage to one single tube necessitates drawing the fires and emptying the boiler. However, on account of their immense advantages as regards lightness and capability of supporting intense firing, when properly designed, they may certainly be called the boilers of the future.

On Some Necessary Conditions for Resisting Intense Firing.

The intensity of firing in water-tube boilers is limited by the formation of "steam chambers," or stationary steam, in the heating tubes, and by the strains due to the expansion of these tubes.

The temperature of a heating surface, behind which only steam exists, rises to such an extent that it rapidly becomes oxydised, externally by the hot gases, which are always mixed with oxygen, and internally by the steam. Moreover, the strength of the metal when thus over-heated is reduced, so as to render rupture probable.

The formation of those "steam chambers" may be prevented by the following means:—

(*a*) The direction of the tubes, especially in their lower and more heated part, must be as vertical as possible.

(*b*) The circulation must be very active.

(*c*) The proportion of length to diameter in the heating tubes ought not to be too large.

(*d*) The section of the outside down-take or water return tubes, from the upper to the lower reservoirs, ought to be of large proportions.

In order to prove the above propositions, I shall consider (Fig. 1, Plate XXIV.) the two older arrangements of the "Du Temple" boiler. Commandant Du Temple was

the first to apply to steam boilers that most important principle of the return of water outside the fire, perhaps the greatest improvement for the last thirty or forty years.

The oldest form of large boilers is shown in A, and the second one in B. For the sake of clearness, only one tube is shown in both designs ; but it is important to state that, the length of tubes in B being one-half the length of those in A, their number is doubled, the heating surface remaining the same in both cases. The arrangement B was applied for the first time, at my request, in the torpedo-boats *Lancier* and *Pernow*.

(*a*) *The direction of the tubes, especially in their lower and more heated part, must be as vertical as possible.*

An intense heat applied to the parts *m m'*, nearest to the fire, produces steam which may take two courses, viz., rise to the upper reservoir or go down in the lower one ; it can also divide and go both ways.

In the first case, although the rise of water in the more vertical parts, *n n'*, produces an energetic circulation, the resistance to an upward motion is very great on account of the length of the tube. In the second case, the distance and resistance to overcome are very small, the more so as the pressure in the lower reservoir is always less than in the upper one, but the inclination of the tube opposes this course.

It is clear that, with very slow firing, the motion will take place in the right direction ; but if sufficient heat is applied steam is produced in abundance, and part of the steam will pass to the upper, and part to the lower reservoirs, interrupting the circulation, and allowing the tube to become empty and red hot. When the boat heels the phenomenon will take place soonest on the side where the tubes approach more nearly to the horizontal.

In arrangement B, where the angle with the horizon of that part of the tube considered is much greater (about three times), the bubbles of steam rise much more easily, drawing the water with them, the more so as the tube in arrangement B is only half the length of the tube in arrangement A.

It must be borne in mind that steam bubbles do not rise easily in a slightly inclined tube, even when the inside surface is quite smooth, and this is seldom the case with steel, which is the only reliable material,* especially after the tubes have been some time in service. To ensure an easy rising of the bubbles a greater angle is necessary This is especially important at the lower part of the tube, where the water enters and the heat is greatest. The most important thing is to set the water in motion in the right direction.

* Copper would certainly last much longer, but it is very dangerous, as, in case of bursting, the tube opens out fully, allowing the hot water and steam to escape through double the section of the tube. Ordinary brass becomes brittle and weak when over heated. With mild steel the section of the orifice is generally small. Security against personal injuries surpasses all other considerations in importance.

Mr. Thornycroft has shown that in the upper part of the tubes this rule could be dispensed with (it is evident that the tumble-down shape of the upper part of the Thornycroft tubes would never do in the lower part).

For many reasons I greatly prefer that the shape of the tubes should be always rising through its whole length, but I would be the last to deny that the Thornycroft boilers have done and are doing good service, and that they have had a great influence on the development of water-tube boilers.

To return to the "Du Temple" boilers, experience has repeatedly shown the superiority of arrangement B over the other one. The actual design patented under the name of "Du Temple-Normand" (which is different from "Normand's" boiler) is still better.

(*b*) *The circulation must be very active.*

This is nearly self-evident. The greater the circulation the cooler are the tubes.

It is well known, moreover, how favourable is the agitation of water to the transmission of heat. Laboratory experiments have shown that the co-efficient of transmission varies from one to five, according as the motion of water is *nil* or very great.

Increase in the economic duty of the boiler means easier firing.

(*c*) *The proportion of length to diameter in the heating tubes ought not to be too large.*

Within the ordinary limits of the ratio of length to diameter the resistance to the motion of water is nearly proportional to this ratio. The circulation of water, so essential to the good working of a boiler, is reduced as the resistance increases.

Moreover, all the steam generated in the inferior part of the tube must pass through the upper end. The longer the tube the smaller the density of the fluid in the upper part, and the greater the chances of its being burnt.

(*d*) *The section of the outside down-take or water return tubes, from the upper to the lower reservoirs, ought to be of large proportions.*

When the boiler is at work, the pressure in the inferior reservoir is always less than in the upper one. Should it be otherwise, the water would not flow down by the return tubes.

It is most probable that the steam generated in the heating tubes (or the air mixed with the feed) produces the circulation of water by impulse only.

This force of impulse is so great that when the tube is vertical the ascending

motion of the fluid may be estimated by applying the theory of communicating vessels, according to the difference between the mean density of the heterogeneous fluid in the heating tube and that of the water in the return tubes, due allowance being made, of course, for friction.

When the heating tube is more or less inclined, the adherence of bubbles to the inside surface is such that this mode of reckoning would certainly give a much higher speed than is actually the case, the error being greater as the inclination of the tube approaches the horizontal. This affords another proof of the importance of verticality in heating tubes.

Should the soundness of these views be questioned, one thing, however, is indisputable—the rise of water and steam in the heating tubes produces a difference of pressure between the upper and lower reservoirs, and this difference reduces the intensity of the circulation from which it is a consequence.

Accordingly, it is most important to lessen this difference in giving to the return tubes the greatest possible section.

In a paper read last year at the Southampton meeting, Mr. Thornycroft described some very interesting trials made on two boilers, differing only in this—that in one of them the heating tubes rose above the level of the water in the upper reservoir, whereas in the other one the upper ends of the tubes were under water. The difference of pressure between the upper and lower reservoir was found to be greater in the second than in the first case.

The great engineer of Chiswick concluded from this fact that, since the difference of pressure reduces the circulation (which is quite undeniable), the circulation is greater with tubes rising above the water level.

With all due deference, may I be allowed to state that I draw from these trials entirely opposite conclusions.

The dimensions of the outside return tubes being similar in both cases, and admitting that the total return of water takes place by these tubes, and not partially through some of the heating tubes which may be less exposed to the fire (which does not seem to be a very reliable arrangement), it is clear that the quantity of water which goes down through the return tubes will be proportional to the square root of the difference of pressure between both reservoirs. Now, this quantity of water is, by hypothesis, exactly equal to the ascending water, so that it is, according to the trials, greater in the boiler where the upper ends of the tubes are under water.

This conclusion is in accordance with the following probable theory, that the head of water which causes the circulation in a tube rising above water must be

reduced by a height equal to that of the tube above the water level, due allowance being made for the smaller density of the fluid.

The under-water arrangement does not, perhaps, allow of so great a heating surface for a given encumbrance; but it offers the further advantage that no "steam chamber" can exist in the upper part of the tubes.

On Strains Due to the Expansion of Heating Tubes.

The second cause which limits the intensity of firing is the strains due to the expansion of the heating tubes.

Several well-known arrangements prevent these strains. For instance, that of the Belleville boilers, the use of Field tubes, as in the Collet-Niclausse boilers, and especially the adoption of heating tubes sufficiently long and sufficiently curved (both conditions are necessary) for preventing oblique strains on the junction with the tube plates.

It is also most important that no joints or riveting should be allowed in the actual vicinity of the furnace.

On the Influence of Active Circulation on the Transmission of Heat.

I have alluded already to laboratory experiments according to which the co-efficient of the transmission of heat varies from one to five, according as the water to be heated is quite stationary or in rapid motion. Particulars may be found in the "Traité de Physique industrielle," by Ser, vol. i. p. 225, &c. This is easily accounted for by this fact, that water is a very bad conductor of heat, and can be heated only by putting all the particles successively in contact with the heating surface.

Although the actual conditions of a boiler are very different from those of the experiments, especially as regards the temperature of the heating fluid, it is not less true that active circulation in boilers is most favourable to vaporisation.

This explains how the advantage to be derived from the use of feed heaters is always superior to that which results from the economy in the units of heat saved. This is especially to be noticed with Mr. Kirkaldy's feed heater. In this apparatus steam taken from the boiler heats the feed before its introduction into the boiler. The result is evidently to equalise, in a great measure, the temperature of the water and steam contained in the boiler with no apparent, though with an undeniable economy. The phenomenon may be explained as follows:—

When the water enters the heating tubes it travels, without boiling, through a certain length of those tubes. The lower its temperature is below that of the steam, the

longer this distance ; and, since the circulation is caused by the development of bubbles in the tubes, the intensity of the circulation is reduced as this difference of temperature increases.

For the last two years I have obtained the same result in the most simple manner by introducing the feed in the steam space under the form of spray, as far away as possible from that part where steam is taken for the engines. The feed being already heated by steam having done work in the H.P. and M.P. cylinders, there is scarcely any difference of temperature between the water and the steam in the boiler. As soon as the water enters the heating tubes, bubbles of steam are produced, and the circulation is increased to such a rate that the temperature of the tube is not higher than with cold feed.

This mode of introducing the feed, which has the further advantage of depositing the calcareous salts in the form of powder, when using sea water, requires some very simple but special arrangement, in order to avoid shocks in the feed pipes.

On Combustion.

The temperature of the products of combustion would be enormous, and greatly superior to that at which dissociation of carbonic acid and steam takes place, if it could be completed in the fire-box.

Starting from this undeniable fact, some engineers think that heat should be progressively subtracted by cool surfaces during the combustion of coal.

This is certainly not the case. No cooling should take place during combustion, and the necessary dissociation of carbonic acid and steam ought not to be avoided, provided sufficient air is admitted to secure further recombination.

In fact, the boiler grate ought to give the same result, though by different means, as the gazogene used in metallurgy ; but all the necessary air should be given at once, the greater part passing through the grate, since it increases the draught, whereas that which is admitted above reduces it. It matters little, for the final result, whether air is admitted at one time for producing carbon oxide, and afterwards for completing the combustion, provided no free carbon exists in the hot gases before they are cooled by the cluster of tubes.

A very good proof of the soundness of these views may be found in the combustion of petroleum, which cannot give its total heat unless it takes place in a white-hot refractory receiver, where it is impossible to avoid dissociation.

The use of the brick arch in locomotive fire-boxes has proved equally advantageous for the complete combustion of coal, especially coal rich in hydrocarbons.

For the same reasons it is most important to have high and large fire-boxes,

where the hot gases are well mixed, and remain as long as possible before entering the cluster of tubes.

On the Section of Passage and Length of Travel of Hot Gases.

With a given capacity of boiler, the section of passage may be very great and the length of travel very small, or the section may be very small and the travel very long, with all intermediate proportions between these extreme limits.

In the first case the draught is good, but the heating surface is very seldom thoroughly utilised. In the second case a good air pressure is necessary, but the economic duty is better, because the hot gases are obliged to heat the whole of the heating surface, and because the transmission of heat increases with the agitation of gases, as it does in the case of water.

This was proved a great many years ago by some most important trials made in France by Mr. Geoffroy, of the Northern Railway of France, on a locomotive boiler. (For details, see Ser, vol. i. p. 564.)

The evaporation was measured, first with all tubes open, and second with half the tubes only. In the last case, notwithstanding the enormous reduction of heating surface, the evaporation per pound of coal remained the same, with this difference only, that a greater air-pressure was necessary.

The conclusion to be derived is that, the section for the passage of the hot gases should be reduced, and their travel lengthened as much as is consistent with the draught available.

The rules given above are certainly not the only ones necessary for making a good water-tube boiler, intended to resist intense firing, but they are certainly the most important.

In order to avoid all misunderstanding, I will show how they have been applied in Normand's boiler. My intention is not to make known an apparatus that has already been many times successfully tried in France and abroad, but I have chosen it because I believe it embodies more completely than any other the above principles.

In general appearance (see Figs. 2, 3, 4, and 5, Plate XXV.) the boiler is the same as that used since 1892, but the arrangement of the cluster of tubes is new, and has been applied on the three torpedo-boats lately delivered (Nos. 183, 184, and 185). This arrangement gives a higher economic duty than the former one.

Fig. 2 is a vertical longitudinal section.

Fig. 3 is a transverse vertical section through the part L of the cluster of tubes.

Fig. 4 is the same, through the part M.

Fig. 5 is a longitudinal section of one cluster of tubes through X Y.

The particulars of the boiler shown in the drawings are :—

Grate surface	39 sq. ft.
Heating surface	1,840 ,,
Number of tubes	1,284
External diameter of tubes	$1\frac{3}{16}$ in.
Internal ,, ,, ...	1 in. bare.
Pressure	200 lbs. per sq. in.
Weight, with all valves, bricks, fittings, &c., without water	10 tons 9 cwt.
Total weight, with water	13 ,, 2 ,,

In No. 185 (single screw) the power of the engine was measured and found to be, at the official full-speed trial, 1,680 I.H.P.

Air pressure	$3\frac{1}{2}$ in.
Consumption of coal per hour	2,600 lbs.
,, ,, ,, per square foot of grate	67 ,,
,, ,, ,, per indicated horse-power ...	1·56 ,,
Indicated horse-power per square foot of fire grate	43 ,,
,, ,, ,, ,, heating surface ...	0·91
Mean temperature of feed	241° Fahr.
,, ,, gases in funnel	708° ,,

The fire bars were too close ; more air will be admitted in future.

At 14 knots the consumption of coal is under 1 lb. per indicated horse-power per hour.

I will now show that the arrangements of this boiler are in accordance with the rules set down above.

As indicated by arrows, the hot gases enter, on both sides of the boiler, the cluster of tubes L at the front end only, and through the whole height. They afterwards travel horizontally to the other end where the funnel is situated.

An inverted bridge, F, pierced with small holes, H, forces the gases to heat the lower part of the tubes before entering the funnel. Otherwise the upper part only would be heated.

The general direction of the tubes, especially in the more heated part, is such that bubbles of steam will rise easily, and that none of the steam produced can return to the lower reservoirs.

The height of the fire-box is very great, and the greater part of the flames and hot gases remain a long time in it, being obliged to come to the front before entering the cluster of tubes. The motion thus imparted to the flames is favourable to complete combustion.

The ratio of length to inside diameter in the longer tubes is 68, whereas in the

former type A, of Du Temple boiler, it was 320, and in type B 160. The curves of the tubes are sufficient to prevent any undue strains from expansion.

The diameter of the three return tubes is such that the difference of pressure between the upper and lower reservoirs must be very small. In boilers now building at my works, the return tube at the funnel end has been dispensed with.

The section of passage of the hot gases is not so large that any part of the heating surface could be left out. Their length of travel is great, and the motion being perpendicular to the axis of the tubes is favourable to their agitation, and consequently to the transmission of heat. On the other hand, it requires a higher air pressure.

Should a better draught be found necessary the width of the clusters of tubes might be increased.

The upper end of the tubes is under water, and the shape of the tubes is such that the formation of "steam chambers" is impossible.

Water circulation begins as soon as the fire is lighted. It becomes intense at full power. When the vessel is laid up, the boiler may be completely filled with pure water saturated with lime. No air can remain in the tubes. This is of great importance as regards durability.

It is indeed difficult to see why the firing could not be increased from what it was in the trial, above mentioned, if the tubes only are taken into account. From my own experience, it is the durability of the fire bars and bricks which limits the intensity of the fire.

Objections have been made about the necessity of removing several tubes, should one middle tube be damaged. The quality of mild steel tubes is such that they may be taken out and replaced without the least difficulty. No better proof can be given of the feasibility of this plan than the following:—the three boilers of Nos. 183, 184, and 185 were finished, when it was decided to alter the arrangement of the clusters, according to the new design. With very simple tools, hundreds of tubes were removed and replaced after having had their shape altered, without any of them being damaged.

Most of the principles laid down in this paper may appear to be so simple as to render their statement useless. It is not so, if we consider how very few of the different types of water-tube boilers are designed in accordance with all of them.

However, my object is not to criticise any of these types, when not intended for intense firing, although the best boilers for intense firing are also generally the best for slow work. Many water-tube boilers are now making steam with tubes nearly horizontal, very low fire-boxes, great section of passage and short length of travel. Each can boast of particular advantages which cannot be disputed.

But the conditions imposed for boilers become more and more severe. In order to save weights, the combustion of fuel per square foot of grate increases every day; 20 lbs. is no longer sufficient; twice, perhaps three times as much will be soon expected for the most powerful engines. A good design will give the owner, the engineer, or the navy that adopts it a great advantage. It is worth while to examine how it will be possible to meet impending exigencies.

THE NICLAUSSE WATER-TUBE BOILER.

By Mark Robinson, Esq., Member.

[Read at the Summer Meeting of the Thirty-sixth Session of the Institution of Naval Architects, June 13, 1895; the Right Hon. Lord Brassey, K.C.B., President, in the Chair.]

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1. So much importance attaches now to the subject of water-tube boilers, that the following notes may be of interest to members who intend to take part, to-morrow, in the visit to the Niclausse Boiler Works in Paris. It must be understood that the writer claims no such intimate knowledge either of the Niclausse boiler, or of water-tube boilers in general, as would enable him to speak with authority upon their respective merits, but he has had occasion to satisfy himself upon various points connected with the former, and his experiences may serve to answer questions likely to be asked by those who see the boiler for the first time to-morrow.

2. The Niclausse boiler was described briefly in Mr. Milton's paper on Water-Tube Boilers, read before the Institution in March, 1894, but it will be useful to describe it more fully here. In general design it recalls the well-known Babcock & Wilcox boiler, in that it has water tubes slightly inclined from the horizontal, which deliver, by a number of ascending headers at the front of the boiler, into a water and steam drum at the top. In the Babcock & Wilcox boiler the drum extends from back to front, and at the rear end there are descending headers which take the water to the lower, or rear, end of the tubes, and thus maintain circulation.

3. In the Niclausse boiler there are no rear headers: the water tubes are closed at the back end, but circulation is maintained by making the front headers *double*, that is, there is a vertical division in them, dividing them into front and rear portions; the tubes are fixed in the rear part of the header. In each tube is an inner tube, which reaches nearly to the back end of the main tube, and which, in front, comes as far forward as the division referred to. The front portion of the header provides for the descent of the water from the drum; thence it passes along the inner tubes to the back end; returns by the outer tubes; ascends by the rear portion of the header; and delivers into the drum. The circulation is shown graphically in Fig. 1, Plate XXVI. It will be seen at once that the boiler is in principle a modification of the Field boiler, with inner circulating tubes.

4. It is an obvious advantage of this construction that the various joints, &c., are brought to the front of the boiler, but there would, perhaps, be not much gain from this if the tubes were expanded into the headers in the usual way. They are, however, fixed by a remarkable joint which allows of almost instant removal, so that they can be, not only examined, but also drawn out through the front. The details of this arrangement will be referred to presently.

5. Another advantage of what may be called the "one-header" system, is that by making an easily broken connection between the header and the drum, the header, with its associated tubes, can be dealt with as a single "element," and removed as one piece—though in practice it is so easy to remove the tubes separately, that it is more convenient to take out the tubes from the header before removing the latter. It may be said, moreover, that the removal of a header is very rarely required: all purposes of cleaning are fulfilled by removing the tubes.

6. The method of jointing the tubes will be seen from Figs. 2, 3, and 4, Plate XXVI. Fig. 2 gives an external view of a tube complete. It consists of two parts, permanently connected, namely, the iron or steel tube T, and the "lantern" A B, the latter being a malleable iron casting. The tube is thickened at the end B, and screwed into the "lantern" with a fine thread. B (of larger diameter than the rest of the tube) is turned to a slight taper, and fits a similarly tapered hole in the back of the header. At D the lantern is cylindrical, and slightly larger than any part of the taper B; D is an *easy* fit in a hole in the internal vertical diaphragm, which divides the header into two parts. A is also tapered, its smallest diameter being larger than D; it fits into a coned hole in the front of the header; thus the entire tube can be withdrawn from the front. The several cones, &c., as well as the holes in the header and its diaphragm, are made strictly concentric. The front end of the header is provided with ears or projections for pulling it out by, and there is in it a large central hole, threaded. Into this screws the plug C (see Fig. 3), which, by means of another smaller and slighter "lantern," carries the inner tube. At E the inner tube fits easily in a bored division in the outer lantern, inside D. In Fig. 2 the solid part of the inner tube is seen through the right-hand opening, G, of the main "lantern"; the left-hand opening, H, showing only the thin edge of the lantern piece of the inner tube. (The inner tube is of very light construction, not being exposed to pressure.) It will be seen on reference to Figs. 2 and 4 that, as already mentioned, the inner tube is able to receive water from the front half of the header through H, and that the same water, with steam, returning from the far end of the inner tube along the outer tube, is able to deliver into the back, or ascending header, through the openings G. So long as the length of the outer tube is not excessive, there is good support for it in the header; it may be mentioned, however, that the weight of the rear extremity of the tube is borne by entering it loosely in a hole in a plate at the back of the combustion chamber. If only

a few of the tubes take a bearing in this plate, it is sufficient to relieve the header from weight. Fig. 4 shows both tubes in section, with the coned and other seats in the header. It need not be said that with tubes held at one end only, there is complete freedom from troubles due to unequal expansion.

7. It will be noticed that the rear end of the outer tube is closed by a screwed cap, the removal of which, when the tube is taken out, renders the operations of cleaning still easier. In land boilers, if there is plenty of space, access is arranged at the rear of the boiler, so that the caps can be taken off from behind; but this is not important. Inspection of the tubes is usually performed by merely unscrewing and removing the inner tube; but it is almost as little trouble to withdraw the complete tube.

8. Owing to the slightly greater area of the front cone, the tubes have, theoretically, a tendency to come out under the boiler pressure only. As a fact, the friction of the cones in their seats is sufficient to hold them in place; but to make sure, clamps are provided, each of which secures two tubes. The arrangement is clearly shown in Fig. 5, Plate XXVI., which is a perspective view of one header with tubes—one "element," in fact. Fig. 6, Plate XXVI., shows the clamps removed, and the process of unscrewing one of the inner tubes; it also shows one of the latter partly withdrawn. In Fig. 7, Plate XXVI., one of the large tubes is shown partly withdrawn, also the operation of withdrawing it from its seatings by a kind of hooked lever placed under one of the ears. This is the plan hitherto followed with the French-made boilers; but the English makers have adopted a slightly more elaborate tool for lifting the tubes, which applies the pull in the line of the axis of the tube, and avoids uneven pressure. It is to be noted that the cone B, in Figs. 2 and 4, is turned out of the thickened part of the main tube, and is not a part of the malleable cast "lantern." This makes it impossible for the tube to draw out through the hole, rearwards, under the steam pressure: its safety is not dependent upon its connection with the lantern.

9. A somewhat similar arrangement of coned joints connects the headers with the drum above. The two are drawn together by bolts and nuts, and a double-ended cone-piece enters seatings in both the drum and the header. Apart from other merits, this system of connections facilitates both the erection of the boiler by unskilled labour, and the easy transport of the parts.

10. With tubes which are fixed by one end only, it is obvious that they cannot be very long, and in fact about seven feet is the extreme length. The length of the tubes approximately corresponds with the length of the grate, and does not admit of more than one "pass" of the gases amongst them; there is no opportunity to take the gases first up and then down again amongst the tubes. The boiler is therefore a short one from back to front, and, apart from the thickness of the containing walls, its fire-grate is

practically as large as the whole floor space the boiler occupies. The shortness of the tubes also makes easy the cleaning of their external surfaces. Every part of them is easily reached from the front by a portable steam jet while the boiler is steaming—a fact which tells very favourably upon the efficiency of the boiler in continuous work.

11. When the Niclausse boiler was brought under the notice of the writer and his colleagues, some two years ago, they were naturally struck with the advantage of a plan which made every part so readily accessible for cleaning, and which admitted of tubes being withdrawn and replaced by new ones made interchangeable, literally in a few minutes. The readiness with which interchangeableness could be secured in the parts, and the extraordinary facilities for repairs, also appealed strongly to engineers accustomed to repetition work on a large scale. But notwithstanding much evidence of successful work in France, they could not but feel grave doubts on four important points, viz. :—

A.—The continuous tightness of the cone joints under all conditions of temperature and pressure ;

B.—The freedom of the boiler from injurious deposits in the tubes ;

C.—The evaporative efficiency, seeing that the gases could pass but once between the tubes, and might be expected to go away very hot ; and

D.—The dryness of the steam ;

and they decided to have over a French-made boiler, and to subject it to long and practical tests. As their primary object was the possession of a good and reliable boiler for electric light stations and other works on land, they ordered a land boiler rated at an evaporation of 1,000 kilogrammes per hour, or about 2,200 lbs.—an evaporation easily attained, on trial, by the combustion of only 13½ lbs. of coal per foot of fire grate.

A.—Tightness of Cone Joints.

12. The boiler was under trial at Messrs. Willans and Robinson's works at Thames Ditton, more or less continuously, for over a year, before it was decided to take up the manufacture in England, and in that time all doubts as to the efficiency of the cone joints, under a pressure of 200 lbs. per square inch, were disposed of. The writer must admit that it seemed to him at first almost incredible that both the front and rear cones should take a perfectly tight bearing together, and retain it under all variations of temperature, but they did so invariably, and practically no leak was ever seen in any joint of the 108 tubes of the boiler. After a year's trial, partly in ordinary working ; partly in tests of various kinds, involving frequent withdrawals of tubes ; partly in standing idle, the joints were as good as at first. The screw-plugs carrying the inner tubes, and the screw-caps on the larger tubes, were equally free from leakage. Anti-corrosion grease is used upon the cones, screw-threads, &c., when they are put

together, and again directly they are removed, and importance is attached to this by the inventor.

13. As regards ease of removal, the writer has several times seen the fire drawn and the boiler blown out, the latter being at the time full of water and under 200 lbs. pressure; one or more tubes removed, inspected, and replaced; an steam got up again to 200 lbs. within a few minutes over the hour. Even this time was longer than would have been required, had it not been necessary to blow out through a very small pipe.

B.—Freedom from Deposit.

14. In this respect also, the trials at Thames Ditton were satisfactory. The writer had been prepared to accept the view that the advantages of water-tube boilers, at least for some purposes, must ensure their use even if they were proved to require more frequent cleaning than ordinary tubular boilers, provided only that the cleaning were made easy enough, and he considered that, with inspection and cleaning made so easy as it is in the Niclausse boiler, even a considerable tendency to deposit need not be a bar to its use. But trial proved that the boiler is really very free from this tendency, perhaps partly because of the quick circulation due to the "Field" tubes; partly because of the means taken to throw down the deposits of lime, &c., upon first entering the boiler, in a place whence they can be easily removed. The feed-water is delivered through the steam space into a receptacle in the drum, in which (being heated by passing through the steam) it throws down its salts, before overflowing into the drum itself. The receptacle is arranged for easy and frequent blowing off, and it is accessible through a hand-hole, for the removal of the more solid deposit. The boiler at Ditton was at first fed with Thames water direct from the river, and afterwards with Thames water from the mains, which, while still hard, had lost the organic matter which keeps the deposit from unfiltered Thames water soft and easy to remove. As the tubes remained surprisingly clean, even when the boiler was worked for a fortnight with the blow-off cocks closed, and also later, when a measured quantity of oil was passed into it daily, the receptacle above referred to was removed from the drum, and the feed-water was sent into it direct. The boiler was then worked, though not continuously, for three or four months, and at the end of that time the deposit in the tubes, though hard, and of course greater than was desirable, was by no means very large in quantity. It was when in this condition that the evaporation trials, to be presently referred to, were made.

15. It is not suggested that the foregoing experiences are conclusive with regard to marine work, in which the difficulties are different in kind, but they show generally that the boiler has little natural tendency to throw down deposit in the tubes. It may be here mentioned that, the boiler was worked for a fortnight with the smokiest kind of North-Country coal, specially procured, but that no difficulty was experienced in keeping the tubes externally free from soot while the boiler was doing its ordinary work.

This test was regarded by the writer as a specially important one, in view of the difficulty which effectual cleaning involves in some types of water-tube boilers.

C.—Evaporative Efficiency.

16. Trials made at Thames Ditton, under ordinary working conditions, gave an evaporation of from 10½ to nearly 11 lbs. of water (from and at 212°) per pound of Welsh coal. This result was so contrary to the expectations of the writer, that, although there was every reason to accept the trials as accurate, it was decided to check them by further trial by an independent authority, and Dr. A. B. W. Kennedy, F.R.S., and Professor W. Cawthorne Unwin, F.R.S., were requested to carry out a test. This trial was not intended to bring out maximum results for publication, and the boiler was not cleaned or in any way prepared for it; in fact, it was even overlooked at the time that, for the reason stated in paragraph 14, the tubes had more deposit in them than should be present under ordinary circumstances. The coal was not of the highest quality, and good as were the results of the trial, it is obvious that better might have been obtained. They at least proved that the single pass of the gases amongst the tubes was not to be reckoned as a drawback, and that the Niclausse boiler could compare favourably with others in regard to economy. The results of two trials at normal output (2,200 lbs. per hour) and of one at an output exceeding the normal *by* 89 *per cent.*, were as follows :—

	Two trials at Normal Evaporation (2,200 lbs. per hour).		Trial at Increased Evaporation of 4,113 lbs. per hour.
Feed-water per pound of coal ... . lbs.	8·67	8·69	8·53*
Do. from and at 212° ... ... ,,	10·47	10·50	10·34*
Do. per lb. of carbon value, from and at 212° ,,	10·95	10·98	10·82*
Coal burnt per sq. ft. of grate per hour ... ... ,,	13·5	13·3	25·6*

* Figures in this column to be taken as approximate only, as the trial lasted only three hours. The other trials lasted about 7½ hours.

A copy of the Report is annexed as an Appendix, with tables. It must in fairness be borne in mind that it was not a trial under the best trial conditions, but very much the reverse—which possibly adds to its value.

17. Perhaps the most striking fact was the very small reduction in the evaporative efficiency when the output was nearly doubled, and when the mean temperature of the chimney gases rose from little over 500° Fahr. to 732° Fahr. As pointed out in the Report, the combustion at this time, though obtained from steam jets, might equally

well have been obtained with a chimney able to give a draught equivalent to 0·75 inches of water. It must be remembered that the grate is large relatively to the size of the boiler (an advantage shared, of course, by all water-tube boilers of what may be called the single-pass type), and that consequently a combustion of 25 lbs. per square foot of grate corresponds with a higher rate of combustion in a boiler in which the grate is relatively small.

18. A few months ago the trial boiler was removed from Ditton to the works of Messrs. Humphrys & Tennant, of Deptford, who fitted it with a casing of marine pattern, and built round it a structure representing a closed stoke-hold, in which trials could be carried out under forced draught. The best results obtained at Ditton were repeated without difficulty, and when burning as much as 35 lbs. per square foot of grate, the evaporation, from and at 212°, was 9·59 lbs. of water per pound of actual coal burnt during a four hours' trial. By the kindness of Messrs. Humphrys & Tennant the writer is enabled to include a table giving particulars of a series of trials at their works. It will be noticed that better results were obtained than in the trials by Dr. Kennedy and Professor Unwin, owing to the boiler being in cleaner condition.

TRIAL OF NICLAUSSE BOILER BY MESSRS. HUMPHRYS, TENNANT & CO.

Grate Area 19·2 Sq. Ft.

Date of Trial. 1895.	Duration.	Steam Pressure.	Temp. of Feed.	Coal Burnt per hour.	Coal per hour. Per ft. of Grate.	Water Evaporated per hour.		Water per lb. of Coal.	
						From Feed Temp.	From and at 212°	From Feed Temp.	From and at 212°
		lbs.		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
15 March	8 hours	165·4	71·30	364	18·96	3368·89	4030·81	9·25	11·06
20 ,,	8 ,,	171·0	60·40	248¼	12·94	2307·63	2789·08	9·28	11 20
25 ,,	4 ,,	171·5	58·20	672	35·0	5329·73	6454·21	7·93	9·59
29 ,,	8 ,,	169·3	69·50	560	29·2	4630·92	5552·31	8·27	9·90
5 April	8 ,,	170·8	60·40	486	25·31	4212·83	5091·59	8·6	10·45

D.—Dryness of Steam.

19. This is sufficiently dealt with in the Report of Dr. Kennedy and Professor Unwin, who summed up the results by saying that "in all cases the amount of actual priming was so small as to be quite negligible." The absence of priming under the assisted-draught trial is remarkable; it did not exceed 0·14 per cent. In the other trials it reached on one occasion 0·43 per cent. The *total* moisture in the steam (not

merely boiler water projected into the steam, which alone constitutes true priming) was found by the wire-drawing calorimeter to be about 1 per cent. (highest 1·2) in the trials at normal output, and there is no reason to assume that it was larger in the assisted-draught trial.

20. The most interesting trials of the Niclausse boiler, from the point of view of this Institution, are those on the French cruiser *Friant*, but here unfortunately we pass beyond matters within the writer's own knowledge. Moreover, in the halls of our kind and hospitable entertainers, from whom we have so many things to learn in the peaceful application of the engineering arts, it would neither be right of us to ask detailed information upon such a subject as the trials of war-ships, nor, if such information were generously given, would it be fitting to publish it. It is believed, however, that there is no impropriety in saying that the 20 boilers of the *Friant* weigh, including casings, firebrick linings, steam drums and valves belonging to the boilers themselves, not quite 200 tons. To this must be added 10·5 tons for the uptakes, and 45·4 tons for water. The chimneys (three in number) are not included in these weights. Including water, the total weight comes out at less than ·33 ton per square foot of grate. The larger boilers, of which there are four, have three fire doors, but only two large doors above, exposing the 12 headers, or elements, composing the boiler. Each header contains 18 tubes, or 216 in each boiler. The outside diameter of the tubes is 3·22 inches, but one tube in each header is special, and has a diameter of 2·95 inches only. The length of each tube is about 7 ft. 4½ inches. The length of grate is 6 ft. 6½ inches, and its surface 45·75 square feet. The heating surface in each large boiler is 1,340 square feet. There are 16 smaller boilers, each containing 10 headers, or elements, instead of 12, the total grate area of the 20 boilers being 775 square feet, and the total heating surface 23,200 square feet.

21. The evaporation, upon the trials of the vessel, is of course not known, but 9,438 I.H.P. was obtained upon a four hours' trial, with a combustion of coal of 25 lbs. per square foot of grate only, this low rate being due, of course, to the relatively large area of the grate and to the economy of the engines and boiler combined, even at this high power the consumption of coal being only 2 lbs. per I.H.P. per hour. Assuming 9 lbs. evaporation (which seems quite reasonable, in view of the trials at Thames Ditton and at Deptford), there would be an hourly evaporation of about 174,000 lbs. of water, or about ·3 lb. of water for each pound weight of boilers, including uptakes and water in the boilers.

22. It is also permissible to give the following general results in connection with the trials of this ship. Six trials were made under the conditions, and with the results, stated below :—

Trial.	Conditions of working and stipulated performance.	Actual results obtained.
1. Consumption Test... ...	I.H.P. to be about 3,500; consumption of coal per I.H.P. hour to be between 1·54 and 1·76 lbs.	I.H.P. 3,657; consumption of coal per I.H.P. hour, 1·46 lbs.
2. Consumption Test... ...	I.H.P. to be about 1,500; consumption of coal per I.H.P. hour to be between 1·65 and 1·87 lbs.	I.H.P. 1,624; consumption of coal per I.H.P. hour, 1·58 lbs.
3. Consumption Test... ...	I.H.P. to be about 7,000; consumption of coal per I.H.P. hour to be between 1·87 and 2·09 lbs.	I.H.P. 7,189; consumption of coal per I.H.P. hour, 1·89 lbs.
4. Maximum Power Test ...	Total power, 9,000 I.H.P.; consumption of coal to obtain this power not to exceed 30·67 lbs. per sq. ft. of grate surface per hour.	I.H.P. 9,438; consumption of coal 24·94 lbs. per sq. ft. of grate surface per hour.
5. Firing Test...	Twelve boilers only to be used; the boilers to be able to burn at least 30·67 lbs. of coal per sq. ft. of grate surface per hour.	Mean combustion, 32 lbs. of coal per sq. ft. of grate surface per hour. (It is worthy of remark that one boiler burnt 35·98 lbs. per sq. ft. of grate surface per hour throughout the whole trial.)
6. 24 Hours' Trial at Normal Power	During first period of 6 hours the minimum power to be 6,000 I.H.P., and for two hours to be not less than 8,500 I.H.P. For second period of 18 hours the mean power to be 6,000 I.H.P., and the coal consumption to be between 1·76 and 1·98 lbs. per I.H.P. hour.	Mean I.H.P. for six hours, 7,826, for three of which the power was 8,547 I.H.P. Mean I.H.P. 6,279; consumption of coal 1·84 lbs. per I.H.P. hour.

23. Two points are reported as worthy of remark in connection with these trials. The first is that in none of them was there any flame in the funnels, nor excessive heating in the casings, showing the efficient combustion of the gases, and the completeness with which the heat in them was absorbed by the tubes. The second is that all the trials were made without any injection of air above the grate, a point of some importance

as affecting the cost and complication of the installation. It is also stated that there was not a single leak found throughout the trials, nor was there any bending of the tubes under the heaviest forcing.

APPENDIX A.

REPORT

By Dr. A. B. W. Kennedy, F.R.S., and by Professor W. Cawthorne Unwin, F.R.S.,

on

TRIALS OF A NICLAUSSE BOILER,

In April and May, 1894.

At the request of Messrs. Willans and Robinson we have made a number of experiments on the boiler constructed on the Niclausse system, which is set up at Thames Ditton, and give the principal results in the following Report:—

The Niclausse Boiler is a boiler of tubular type which may be most concisely described as consisting of a number of tubes, resembling Field tubes, but placed at an angle of about six degrees to the horizontal, and so connected at the front end that the inner and outer tubes communicate with separate headers. The water in the outer tube, being the hotter, rises through the inner headers to the steam drum at the top of the boiler, and circulation is maintained by a descent of water through the outer headers, which communicate with the inner tubes, the front and back headers being separated by a vertical diaphragm, through which the inner tubes pass. At the joints between the tubes and headers, the parts are turned and bored so that the tubes can be withdrawn and replaced with facility.

In the boiler which we tested, the outer tubes were 3·22 ins. diameter, and 7 feet long; the inner tubes were 1·5 ins. diameter, and extended nearly the whole length of the outer tubes. The total external tube surface in the boiler was thus 649 square feet. At the top of the boiler was a steam drum 3 ft. 3 ins. diameter, and 6 ft. 6 ins. long. The boiler was set in brickwork and was standing entirely separated from other erections on a wharf beside the river, a condition of affairs which can hardly have tended to reduce the radiation losses.

The points on which we have been specially asked to report are the evaporative efficiency of the boiler, and its output in proportion to its bulk. In the following Report, these points will be found to be dealt with.

The evaporative trials took place on the 10th and 11th April and the 12th of May. It has turned out that the two earlier trials gave almost absolutely identical results. The second one was made because of an accident to a spring balance, just at the close of the first, which, at the time, we thought might possibly have vitiated its results in some way.

The water was measured out of a tank which was carefully calibrated before and after the trial. The time at which each 500 lbs. of water passed into the boiler was noted.

The coal was measured by the direct weighing of sacks of 100 lbs. net each, and the time noted at which firing from each 100 lbs. weight commenced and ended.

The steam pressure gauge was checked against a mercury column by Prof. D. S. Capper, of King's College, and the necessary (small) corrections have been made in the figures given below.

Samples of the furnace gases from the chimney were collected on each trial for analysis, and samples of steam were also taken for the determination of priming, both by a wiredrawing Calorimeter and by salt test.

The whole of the pipes in the boiler which were not in use were either opened out to the air or blanked off before the trials commenced.

Table I. shows the principal results of three evaporative trials. On the 10th and 11th April, the trials were made at what was considered the normal full output of the boiler. On the 12th of May, a special trial was made by our request, to find how far the boiler could be forced by the use of steam jets without causing any appreciable amount of priming to occur.

Confining ourselves in the first instance to the trials under normal conditions, it will be seen that the duration of each test was about 7 hours and 20 minutes, and that coal was burnt (with ordinary hand firing) at the rate of about 13·4 lbs. per square foot of grate per hour.

In each trial, 16,000 lbs. of water was pumped into the boiler. In the one, 1,845, and in the other, 1,841 lbs. of coal were burnt. The actual evaporation was thus 8·68 lbs. of water per lb. of coal, which corresponds to an evaporation of 10·96 lbs. of water under standard conditions per pound of carbon-value of fuel.

Table II. shows the heat balance for the trials, and from this it will be seen that 73 per cent. of the total heat of the fuel was utilized in steam generation. There was a certain amount of loss in each case by imperfect combustion. In each case the largest loss was in the waste gases carried away up the chimney. The amount of heat thus lost averaged about 17 per cent. in the two trials. The figures in Table II. are of course entirely based on the gas analyses given in Table IV., which have been made for us by Mr. C. J. Wilson, F.C.S., and their exactness depends on the exactness with which the samples of gases collected during the trials really represent the average condition of the gases throughout its whole duration. It is of course impossible to suppose that the results are quite accurate, but the close correspondence between the two days indicates that they must be very approximate.

We did not think it was necessary to have the coal chemically analysed, but its thermal value was determined by Mr. Wilson, and the results are given in Table III. It will be seen that the coal, which was described as "Powell Duffryn," had by no means a very high evaporative value, its carbon value being, in fact, only 0·956. The ash shown by the analyses is somewhat unusally large for this quantity of coal. The table also gives an analysis of the ash and clinker brought home from the trials.

Table II. gives Mr. Wilson's analyses of the chimney gases collected on the two trial days.

Table V. gives the results of the determinations as to wetness of steam. It will be seen that in all cases, the amount of actual priming was so small as to be quite negligible.

On the 12th of May, we made a trial, as already mentioned, to see what output could be got from the boiler without injury and without priming, with a forced draught. The results of this trial are given in the same tables as those of the 10th and 11th of April, so far as they go. We measured the coal during this experiment simply as a matter of interest. The duration of the trial was of course too short to enable any accurate determination of the evaporative efficiency to be made. The figures in italics therefore must be taken as not more than approximative. On this trial, the duration of which was practically three hours, steam jets were used below the fire-grate, and the ash pit was closed. The jets induced an air pressure of 0·56 inches. The chimney was a very small one, capable only of giving a draught equivalent to 0·2 inches of water, so that the actual duty obtained from the boiler with the steam jets might have been equally well obtained without steam jets from any boiler provided with a chimney which could give a draught equivalent to 0·75 inches of water. The actual rate at which water was evaporated during this trial was 4,113 lbs. per hour, or 89 per cent. in excess of the normal rate, as represented by the former trials. It will be seen that the priming remained practically a negligible quantity, and there were no signs in the working of the boiler that it was being in any way unduly forced. The quantity of steam used by the jets was not separately measured, as the trial was intended to determine maximum output obtainable under conditions when special economy became of secondary importance.

In addition to the five tables appended to this Report, we add copies of diagrams which show graphically the chief results of the trials.

(Signed) ALEX. B. W. KENNEDY.
W. CAWTHORNE UNWIN.

TABLE I.

PARTICULARS OF TRIALS.

	Date of Trial, 1894.		
	April 10.	April 11.	May 12.
Hour at which steam pressure got up in boiler ...	6.30 a.m.	6.15 a.m.	—
Weather	Very fine	Very fine	Very fine
Barometer (mean), ins.	30·14	29·94	30·09
Time of starting trial	9.10 a.m.	9.9 a.m.	9.53 a.m.
Duration of trial	7·27 hours	7·40 hours	2·95 hours
Total water evaporated	16,000 lbs.	16,000 lbs.	12,134 lbs.
Total coal burnt	1,845 lbs.	1,841 lbs.	1,422 lbs.
Carbon value of coal used	0·956	0·956	—
Total feed-water per lb. of coal	8·67 lbs.	8·69 lbs.	8·53 lbs.
Total feed-water per lb. of coal, from and at 212° ...	10·47 lbs.	10·50 lbs.	10·34 lbs.
Total feed-water per lb. of carbon value, from and at 212°	10·95 lbs.	10·98 lbs.	10·82 lbs.
Coal burnt per sq. ft. of grate surface per hour ...	13·5 lbs.	13·3 lbs.	25·6 lbs.
Feed-water per sq. ft. of heating surface per hour ...	3·39 lbs.	3·33 lbs.	6·34 lbs.
Feed-water per cubic ft. of boiler and boiler setting per hour	2·61 lbs.	2·57 lbs.	4·88 lbs.
Mean steam pressure above atmosphere, lbs. per sq. in.	158·6	159·6	144·3
Mean steam pressure absolute, lbs. per sq. in. ...	173·4	174·3	159·1
Mean temperature of feed-water, in deg. Fahr. ...	60·3	60·3	55·0
Mean temperature of air, in deg. Fahr.	67·4	67·6	62.3
Mean temperature of chimney gases, in deg. Fahr. ...	511·7	502·7	732·0

TABLE II.

Utilisation of Heat in each Pound of Coal.

	April 10.		April 11.		May 12.	
	Thermal Units.	Percentages.	Thermal Units.	Percentages.	Thermal Units.	Percentages.
Heat utilised in formation of steam	10,110	72·94	10,136	73·11	9,970	71·9
Heat lost by imperfect combustion (formation of carbonic oxide)	501	3·61	185	1·33	...	...
Heat lost by carbon left in ash ...	133	0·96	136	0·98	...	...
Heat carried away by waste gases	2,327	16·79	2,435	17·56	...	...
Heat lost by radiation and otherwise unaccounted for ...	789	5·70	968	7·02	...	...
Thermal value of coal as determined by experiment ...	13,860	100·00	13,860	100·00	13,860	100

TABLE III.

Thermal Value of Coal.

Mr. Wilson reports that the sample of coal sent in contains 0·80 per cent. of moisture, and 6·74 per cent. of ash. He finds also that its thermal value is 13,860 units per pound if burnt in the usual way in a furnace.

Mr. Wilson also gives the following as an analysis of sample of ash and clinker taken on the trial of the 11th April :—

Moisture	0·33	per cent.
Ash (incombustible)	70·74	,,
Loss on ignition (combustible)	28·93	,,
	100·00	

TABLE IV.

Analyses of Flue Gases.

Experiment of April 10.

Sample No.	Carbonic Acid.	Carbonic Oxide.	Oxygen.	Nitrogen.	Total.
		Percentages by Volume.			
1	9·71	0·00	9·82	80·47	100·000
2	9·50	0·00	10·63	79·87	100·000
3	9·07	0·00	10·58	80·35	100·000
4	8·24	2·24	9·45	80·07	100·000
5	8·92	0·00	10·51	80·57	100·000
6	8·43	2·33	9·12	80·12	100·000

The last two samples were collected over brine by Mr. Low, and were analysed to compare with the previous results obtained by him on the spot. In the calculations as to furnace gases made in the Report, only the first four analyses, which were of samples collected over mercury, have been actually used. In these the average carbonic acid is 9·13 per cent. by volume, which is equivalent to 13·21 per cent. by weight. On working out, the air used per lb. of coal comes to 20·8 lbs.

Experiment of April 11.

Sample No.	Carbonic Acid.	Carbonic Oxide.	Oxygen.	Nitrogen.	Total.
		Percentages by Volume.			
7	8·96	0·00	10·43	80·61	100·000
8	9·29	1·44	8·98	80·29	100·000
9 & 10	9·55	0·00	9.84	80·61	100·000
11, 12 & 13	8·21	0·00	11·49	80·3	100·000

The average from these results is 8·85 per cent. of carbonic acid by volume, or 12·82 per cent. by weight, from which calculation we find the air used per lb. of coal to have been approximately 23·3 lbs.

TABLE V.

Priming Results.

(a) By Salt Test.

	Sample No.	Time.	Priming, per cent.
		A.M.	
April 10	1	10.30	Not measurable.*
	2	11.38	0·35
	3	12.34	Not measurable.
		P.M.	
	4	1.51	,, ,,
	5	3.40	,, ,
		A.M.	
April 11	1	10.35	Not measurable
	2	11.47	0·43
		P.M.	
	3	1.40	0·10
	4	3.42	Not measurable.
		A.M	
May 12	1	10.36	0·14
	2	11.40	0·04

* The expression "not measurable" means that the priming was less than 0·03 per cent., which was the smallest quantity which could be measured.

Moisture in Steam by Wiredrawing Calorimeter.

Time.	Pressure by Gauge on Boiler.	Temperatures. dhgs. Fahr. Upper Thermometer.	Lower Thermometer.	Dryness Fraction of Steam.	Moisture in Steam per cent.
Trial on April 10.					
h. m. h. m.	lbs. per sq. in.				
10. 3 to 10. 5	161·6	357·0	279·3	·988	1 2
11.12 ,, 11.20	161·0	357·5	280·6	·989	1·1
12.17 ,, 12.21	160·8	359·6	282·8	·989	1·1
2 52 ,, 2.55	149·0	354·0	281·3	·990	1·0
				Mean	1·1
Trial on April 11.					
h. m. h. m.					
10.14 to 10.20	160·5	360·25	281·75	·990	1·0
11.17 ,, 11.19	158·0	359·75	283·0	·989	1·1
12.14 ,, 12.18	160·0	361·0	284 0	·990	1·0
2.20 ,, 2.25	157·4	360·8	284·3	·990	1·0
3.16	158 3	360·3	284·5	·991	0·9
				Mean	1·0

The Salt test shows only boiler water projected into and carried by the steam. The Wiredrawing Calorimeter shows the total moisture in the steam.

DISCUSSION ON THE TWO PRECEDING PAPERS.

Mr. J. I. Thornycroft, F.R.S., Vice-President: My Lord, Ladies and Gentlemen, I have much pleasure in speaking on this subject of water-tube boilers, because it is one of which I have made a considerable study, and in the remarks I have to make, although there may appear some differences between my opinions and those of M. Normand, I feel that these differences are probably only apparent. On looking through the paper I find that there are some little things I should like him to correct; but on the whole I think the paper is a contribution to the Transactions of our Institution for which we are deeply indebted, because in it M. Normand has shown that the same principle which is applied to his feed heater is applied also to his boiler, and that the transmission of heat to the water in the boiler is the same in principle as that in the feed heater. One improvement M. Normand has made in the boiler, and that is, that he takes trouble to cause the gases to cross the heating tubes in such a way as to agitate them and make them give up their heat in a manner which is most favourable to good evaporation, and which enables him to employ an amount of heating surface less than that which has been required, perhaps, in any other boilers. However, I must call attention to the fact that in what M. Normand has done, he has tried an experiment which, it seems to me, may perhaps lead to trouble; but, as he has succeeded, of course you must give him the credit due to his success. M. Normand has endeavoured to show that his boiler is developed from the Du Temple boiler, but what I desire to show, taking it very shortly, is that, in the boiler of M. Du Temple we have one in which very long tubes were used, contained in an envelope consisting partly of fire-resisting substances; that is, the heated gases were not enclosed in a water casing, as the old-fashioned boilers were, but the boiler consisted merely of a box in which tubes were heated, and in that way the outside envelope was in danger of being overheated. One of the improvements I claim to have made in the water-tube boiler is constructing the envelope really of a water casing, although made of tubes. In the Belleville boiler this was not so, and I feel flattered that M. Normand has followed me in this matter, as he has not only made the Du Temple boiler of larger tubes, as I thought was desirable; but has also adopted the outside envelope, which seemed to me an important thing, and which is most important where the space is limited and you must put your fire near to the coal. He also adopts part of the outside water envelope to the fire-box. In his most recent boiler a departure is made from what I did originally. In my first water-tube boiler I made the tubes all, as far as possible, symmetrically situated round the fire, so that the distribution of heat should be limited in amount and that no tube should be distressed. In this respect M. Normand has departed from my practice. In the front of his boiler he somewhat distresses his tubes, I think, by causing all the heated gases to go between a limited number of them, instead of distributing the heat, as I have done, between the entire masses of tubes. In some boilers we have been making lately we have ourselves been obliged to depart from this practice to a slight extent, because of the limited length of the grate and the large length of boiler which it was necessary to give. Another subject to which I wish to call particular attention is the matter of circulation. At first sight, on reading the paper it appears that M. Normand and myself disagree, but I think we do not. I think that whereas M. Normand says the pressure is equal in the top and bottom vessel, he really means that the pressure in the bottom vessel is only greater than the pressure in the upper vessel by the pressure due to gravity acting on the column of fluid in the connection between the upper and lower chambers. At this point I must call attention to the fact that, so far as I can see, the force of gravity is the real force and the only force we have to depend on for the circulation of water in the

boiler. If we could go to another planet where the force of gravity was larger we might have less trouble with the circulation in our boilers. On the other hand, if we could take the boiler down to the centre of the earth, where gravity may be supposed to be *nil*, or acting equally in all directions, then no construction of boiler we could adopt would enable us to make one that would work. It would be sure to burn. That leads me to this: I take it that the circulation of the water, or whatever is in the boiler, is due to the difference in weight of the two columns in circulation; and, although I agree, for the most part, with all M. Normand has said, I find that departure may be made from what he has assumed to a degree of which, I think, he is not quite aware. For instance, lately I have constructed a boiler where simplicity was intended to be attained. In this boiler I have only two vessels between which tubes are bent, and these tubes form not only the heating surface but the fire bars. When these tubes form fire bars, I have, perhaps unwisely, made them horizontal, but I find the difference of density in the two columns enables the circulation to be maintained. We have been running one for ten months, and the fire bars or fire tubes composing the grate are still in perfect order, and I have confidence in using that boiler for small installations. There is one thing with regard to history which I would beg to call to the attention of M. Normand. Perhaps he has been misled by an examination I made years ago. I prepared a paper in 1889 for the Institution of Civil Engineers, and at that time I was not aware of what had been done in the direction of light boilers for road locomotives. I am glad to see in France they are making rapid development; but, I understand, unfortunately for the boiler-makers, the fire is being put inside the cylinder. Returning to the subject of road locomotives, it is a most difficult thing to travel on the road by any mechanism. The difficulty of travelling on a railway is infinitely less, and the first constructors of carriages that went on the road in England were obliged to see what could be done, and I am glad to say they turned to the water-tube boiler, and in that they found a solution by which they could run on the common road. I think I am right in saying that an early example of the water-tube boiler, in which the external tube was used to return the water to the lower part, was made by Mr. Gurney. The date of that invention was 1825, and that is previous to the date given for a Du Temple boiler by M. Normand. I have no doubt M. Du Temple had no idea of what was done before, and was quite right in claiming for himself an invention which, to him, was entirely novel; and, I think, in science it often happens that the same invention is invented by different people at the same time at different places. Turning again to the two boilers which are illustrated at the end of the paper of my friend, I find the drawing of the Du Temple boiler and of that of M. Normand. I find much to admire in the drawing of M. Normand's boiler, but I also find, if I turn to my paper before the Institution of Civil Engineers there is a great likeness between this drawing and my own boiler, and I feel M. Normand has been driven by force of circumstances to make his tubes deliver above water. In England we have successful work being done in some of the torpedo-boat destroyers, boilered on M. Normand's plan, in which it is said the four upper rows of tubes deliver above water. I am still of opinion, although M. Normand seems to disagree with me, that there are conditions in the working of boilers in which this is preferable to discharging the water below. The water discharged from a heated tube is not a steady flow. Part of the reasoning on which my most esteemed friend relies, depends on this: that it is a steady flow. Being unsteady there are conditions, which it would take me too long to explain, which make it not true that the flow is as supposed by M. Normand. In the experiment I gave at the Summer Meeting at Southampton I intended to show that, under certain conditions, when there were no down tubes the boiler became unsafe. I actually measured the water discharged from the tubes by a notch in the boiler and examined the discharge through a window—a glass plate in the boiler—by which, observing the notch, the amount of water could be measured. By that means I found that, if the water going

down the small tubes, which should not go down, was neglected, the flow in the tubes delivering above water was about twice as great as the flow in the tubes delivering below. I feel that I have taken up so much time that I will not trouble you further.

Mr. A. F. Yarrow (Member of Council) : As our time is exceedingly limited, I will not trouble the meeting with any remarks upon the very excellent paper which we have heard read from M. Normand, I regret the time is so short, because in the paper there are many points which I fully agree with, and also many with which I would take the liberty to entirely disagree. I will, however, confine myself to saying that I am sure I shall express the feeling of the English members present when I say that M. Normand deserves a very high tribute for the paper which he has prepared, and the kindness he has shown in giving the information which he has so readily placed at our disposal.

The President (the Right Hon. Lord Brassey, K.C.B.) : Ladies and Gentlemen, in the name of the Institution I tender our most grateful thanks to M. Normand and Mr. Robinson for their admirable papers. Nothing that I can say on the subject can have the same weight as attaches to the high opinion and warm praise which has been expressed by experts of such high competence as Mr. Thornycroft and Mr. Yarrow. I am sure that M. Normand will greatly appreciate the tribute of admiration for his work and professional skill which has been expressed by the most competent authorities on our side of the Channel.

CONCLUDING PROCEEDINGS.

The President (the Right Hon. Lord Brassey, K.C.B.): Now, Ladies and Gentlemen, the last of the valuable papers which have been prepared for the present meetings have been read. I have a duty to perform; and I am sure that you will all recognise that it is not in any sense a formal duty. The duty which I have to perform is one which is prompted by the warmest feelings of grateful hearts. I have to propose a vote of thanks on behalf of the Institution of Naval Architects to the Committee of Reception which has prepared for us such a happy time here in Paris. On the first day of our meetings I endeavoured, with the best French that I could command, to express to Admiral Duperré and M. Bertin, and others concerned, how deeply indebted we felt to them; and I can assure them of this, that what they have done for us will not only be appreciated—as it is most warmly appreciated by the Institution of Naval Architects—but I venture to say that what they have done will be appreciated by the whole British nation; that it will be long remembered, and be one of those occasions which we seek to multiply, and which really and most effectively draw two great nations near to one another. In addition to the thanks which I now tender to the Committee of Reception, I have to add thanks to other societies and to other persons. Our especial thanks are due to the Ministry of Marine, to the Municipality of Paris, to the Chamber of Commerce of Paris, to the Sorbonne, and more especially to the Rector of the University, Monsieur Gréard, and to the courteous Secretary of the Sorbonne, who has been indefatigable in providing for our comfort in this hall. Further, our thanks are due to M. and Madame Bertin, who entertained us so hospitably; and I may add too, M. Bertin is entitled to our thanks in a double sense, because, as chairman of the Executive Committee, on him has devolved the lion's share of the labour of preparing for our reception. Members will not have forgotten that we originally received our invitation to Paris from four public bodies, namely, the French Society of Civil Engineers, whose general secretary, the Comte de Dax, has been one of the most active members of the Reception Committee; the Society for the Encouragement of National Industry; the French Institution of Naval Architects—President, M. de Bussy; and lastly, the Union of French Yachts. The great French railway companies, Chemin de Fer de l'Ouest and Chemin de Fer du Nord, have been most marked in their kindness to us, having granted to our members large reductions in their fares. I may say that when I paid my fare at Charing Cross I was astonished at the reduction. Finally, we owe our best thanks to M. Tisserand, Director of the Observatory, and the gentleman who directs the Institut Pasteur, and the various manufacturers who have opened their houses to us. Once more, and from a full heart, in your behalf I move a warm vote of thanks to the Reception Committee, of whom Admiral Duperré spoke such kind words at our opening meeting, and on whose behalf, I understand, to-day a reply will be made by M. Bertin. I call on Sir William White to second this resolution.

Sir William White, K.C.B., LL.D., F.R.S. (Vice-President): Lord Brassey, Ladies and Gentlemen, as we English folks know, it is always the custom in England that a resolution should be seconded as well as proposed, but you will all believe that it is not mere formal seconding on my part

of the resolution of thanks so warmly and ably expressed by our noble President. There are many members of this Institution who do not require any special inducement to visit this pleasant city of Paris. I believe that one of the great happinesses that have marked our present visit has been the fact that the invitations sent out by the Reception Committee have not been limited to the gentlemen of the party; and I am informed on good authority—although I do not speak from personal knowledge—that when our Secretary sent out cards of inquiry as to whether a gentleman would bring a lady, that most of the gentlemen found themselves in the position of having to say: *Will* I bring a lady? How *many* shall I bring? The Reception Committee, I am sure, will be charmed to know that the interest of the ladies in our proceedings as an Institution has on this occasion been unrivalled. I never remember in any assembly of the Institution to have seen so many ladies as have attended these meetings. I have just learned that one notice of our proceedings in a Paris paper referred to a certain contribution as being dry; but if the reporter had looked behind and seen the striking and ardent interest displayed with regard to such charming subjects as the amplitude of oscillation, or the sheathing of ships, by the ladies present, I am sure he would have withdrawn the remark. I do not propose to use more words, except to say this again in support of our noble President, that we do all feel most grateful, more grateful than we can say, to Admiral Duperre and his colleagues on the Reception Committee for the great pleasure which they have given to us, for the very exceptional reception we have had, for the *embarras de richesses* we have enjoyed in the way of visits to interesting places undertaken for our pleasure and profit; and, although we may not yet have quite reached the point where Paris has become a port of the sea, which I believe is the intention of our friends on this side, yet they have done this for us: they have brought those who are much interested in the sea to Paris. I am sure that we shall always wish Paris well in every way, and remember our visit here.

The resolution having been put to the meeting, was carried by acclamation.

Vice-Admiral Charles Duperre (President of the Reception Committee): My Lord, Ladies and Gentlemen, the Committee, which the Minister of Marine has conferred on me the honour to preside over, has had great pleasure in devoting itself to the preparations for one of the annual meetings of your learned Institution, to which naval architecture is indebted for so much of its progress. We are all most sensible of the expression of your thanks for a reception the cordiality of which is its principal merit. We, on our side, will never forget the gracious words which Lord Brassey has spoken, nor the expression of sentiments, which will be echoed throughout our country.

Monsieur de Bussy (Honorary Member): My Lord, Ladies and Gentlemen, I am very happy to be enabled to address in Paris my thanks to the Institution of Naval Architects. I have always felt largely indebted to this Institution, at first as an honorary member, and also as being the President of the Association Technique Maritime. Your honorary membership was the first scientific distinction conferred on me. It seemed to me an acknowledgment of the importance of my technical titles, given by a tribunal the impartiality and competence of which are not disputed. Speaking now as President of the Association Technique Maritime, I dare say I am also very much indebted to the Institution of Naval Architects. Indeed, this great Institution, which has proved so serviceable to the advancement of the science of naval construction, served as a model to the French founders of the Association Technique Maritime. We aspired to possess ourselves these eminent qualities, which are the distinctive badge of the Institution of Naval Architects, where the most useful information, fruits of costly experiments, are so liberally given, where the most important questions are so freely and so courteously discussed. My Lord, Ladies and Gentlemen, I think I am now one of the oldest and one

of the most ancient members of this Institution. I recollect with a grateful heart all the dear friends I have found among its members. I pray to be allowed to say what happy remembrance I keep of the good reception I have always met with in England, and to express the most sincere wishes I form for the Institution and its noble President.

Monsieur E. Bertin (Member): My Lord, Ladies and Gentlemen, I hope you will excuse my addressing you in English. It was not my wish to do so, but all my friends insisted upon my speaking in your own language. All of us members of the Committee, whether we are representatives of the Government, of the large corporations, of the scientific institutions, or of the large industrial firms, who have co-operated in the agreeable task of preparing the reception for your Institution of Naval Architects, are extremely grateful for the kind words which Lord Brassey has spoken. We think that his expression of gratitude is far in excess of any trouble which we have taken on your behalf. We can say so with all the more confidence, because, if these meetings have been an undeniable success, it is due in a great measure to Lord Brassey himself, for the principal success has been that of the speeches which he has himself delivered, and for the spirit by which they have been inspired, which instantly gained the hearts of all who were present. Thus, we have in a large measure to return to Lord Brassey the thanks which he has been good enough to bestow on us. We should like to add, that if any shadow has crossed our path during these proceedings, it has been due to the absence of Lady Brassey, who has been detained in England by a painful duty, and by anxieties which, we believe, have now been happily dispelled, but the existence of which has caused us to value still more highly the presence of Lord Brassey himself. Next to the speeches of Lord Brassey, we attribute the success of the meetings to the speakers who have come here to treat subjects of the greatest interest, with consummate ability, combined with the oratorical and debating talent which are due to the habits of public life in England. It is not necessary for me to draw a picture of the comparative merits, or of the individual value, of the services which have been rendered to ship construction and navigation by Dr. Elgar, Mr. Denny, and Mr. Martell—who always stands in the breach for Lloyd's Registry—or by those who have treated the delicate question of the different systems of water-tube boilers. But we have to thank Sir William White in a double sense, first, for the exceptional interest of his work on the sheathing of the hulls of steamships, and secondly, for the energy, of which he has given a proof by writing his paper during a severe illness, and even in braving the fatigues of these meetings at a moment when he was most in need of rest. Gentlemen, we appreciate in a high degree the fortunate consequences which result from the meetings of technical men, and of the free discussions which have been your custom for so long a period. We do not esteem less highly the results of the professional confraternity and good-fellowship, which create, in scientific matters, a common country. Finally, I do not forget the custom, so generally followed in England, of remembering our absent friends, and I will conclude with an expression of regret at the absence of Sir Edward Reed, and with our best wishes for his recovery from the illness which has prevented him being present at these meetings.

PRESENTATION OF AN ADDRESS TO LORD BRASSEY.

Sir Nathaniel Barnaby, K.C.B. (Vice-President): My Lord, Ladies and Gentlemen, I have to apologise to those now present who are not Members or Associates of the Institution of Naval Architects, that we Members and Associates have to perform a piece of business before we separate. It is unfortunate that in the midst of the enjoyment we have in Paris we have to undertake the very painful duty of bidding farewell to our noble President. It is unfortunate for us that he has been selected by Her Majesty to represent her as Governor of one of the great divisions of Australia. We who know him so well are glad to remember that they will learn to know him as we have, but for ourselves we are full of sorrow. I have now to address to Lord Brassey the few parting words of his colleagues:—"My Lord, we, the Vice-Presidents, Council, Members, and Associates of the Institution of Naval Architects, desire, on the occasion of your Lordship's resignation of the post of President of the Institution, to record our high appreciation of, and most grateful thanks for, the manner in which you have carried out the duties of your office. The time during which your Lordship has been our President has not been long; for, to our regret, the call of public duty has obliged you to transfer your activity to a distant part of this great Empire, to facilitate communication between the various parts of which is one of the highest objects of our Institution. But short as the time has been, the Institution has greatly flourished under your leadership, and has enlarged its influence, and extended the sphere of its usefulness, results which we cannot but regard as due, in a very high degree, to the untiring interest which you have taken in our proceedings, and to the fairness and impartiality with which you have always presided over us. Although absent we trust that you will continue to be one of us, and whenever possible will aid in our Councils, and use your influence in advancing the work of the Institution. In conclusion, we trust that in your new office, and wherever you may be, you and Lady Brassey may enjoy health and happiness, and our united good wishes will accompany you to that distant Colony, which we doubt not will flourish, as we have, under your guidance." I formally propose this address as a vote of thanks and good wishes from the Institution.

Rear-Admiral C. C. P. Fitzgerald (Associate): I have been deputed to second the motion that this address be presented to Lord Brassey, and I do so with the very greatest pleasure. I cannot help feeling that one of the reasons of Lord Brassey's eminent success as President of this Institution (if I may say so without undue pride in my profession) is the fact that he is himself a thoroughly practical seaman. Lord Brassey has given undoubted proof of this, and this fact, added to his urbanity, his unfailing courtesy, his absolute impartiality, and last, but not least, his keen sense of humour, of which we had such an amusing example only yesterday, cause us to regret deeply his departure for Australia. But while we do so, we, who have friends in the Colonies, and particularly in Victoria, may derive some slight consolation from the feeling that our loss will be Australia's gain. I have great pleasure in seconding Sir Nathaniel Barnaby's resolution that the address which you have heard read be presented to Lord Brassey.

Sir Nathaniel Barnaby, K.C.B. (Vice-President): May I be permitted to put to the members and associates of this Institution this proposition:—That you adopt for yourselves the words which have been drawn up and read to you, to be presented to Lord Brassey.

The resolution, having been put to the meeting, was carried by acclamation.

Sir Nathaniel Barnaby then presented Lord Brassey, on behalf of the Institution, with an illuminated copy of the address.

The President (the Right Hon. Lord Brassey, K.C.B.): Sir Nathaniel Barnaby, Admiral Fitzgerald, and Members of the Institution of Naval Architects, I thank you from my heart for the address which you have so kindly presented to me. I am deeply touched by this mark—this imperfectly merited mark—of your appreciation and regard. I can assure you it has been to me a source of the greatest pride and satisfaction to hold the important office of the President of the Institution of Naval Architects. No reward that I could have received for many years of devotion to maritime subjects could have been more valued and more precious to me than the kind compliment which you paid me in electing me to be your President, and, believe me, it costs me much to resign that honourable office. In looking forward to my duties in Australia with hope and pride and satisfaction, there are commingled many sad thoughts. I number among my dearest and best friends a large number of the members of your Institution. It is very hard to say good-bye to them. It is very hard to leave my own country, in which my roots have been deeply struck. There are, indeed, very many deeply regrettable circumstances in connection with taking up the post to which I have had the honour of being appointed, and there is only one consideration by which I am sustained in a very difficult time. It is the belief that it is my duty to my country to obey its call. Sir Nathaniel Barnaby has expressed the confident hope that I shall always follow with interest the proceedings of the Institution of Naval Architects. Yes, I can assure Sir Nathaniel Barnaby that I shall always feel myself to be one of yourselves, and wherever I may be I shall do my utmost to promote the interests and advancement of your great Institution. I am touched by what has been so kindly said on behalf of Lady Brassey, and, you will believe me, it will be a great pleasure to me to convey to her, words inspired by such kind thought and sympathy. I must not detain you. I can only say, once more, that I am deeply touched by your kindness in giving me this address, and I shall value it, and all those who come after me will value it, as one of the most precious possessions I could hold. I thank you once more from my heart.

The President (the Right Hon. Lord Brassey, K.C.B.): We cannot leave this hall, Ladies and Gentlemen, without passing a vote of thanks to Monsieur de Pulligny. As I said yesterday, he has a marvellous gift for giving in tens of words in French, most effectively, the sense of thousands of English words. I convey, on your behalf, our most grateful thanks to M. de Pulligny.

Monsieur de Pulligny: My Lord and Gentlemen, I am greatly indebted to you, and I offer you warm and sincere thanks, not only for the amiable vote that has just been proposed in my favour, but also for the indulgent congratulations that several gentlemen have addressed to me in the most grateful and flattering manner. Although a great many among them have attested that there was no humbug in the matter, I cannot prevent myself from believing something that I beg leave to tell you confidentially. As I have ascertained that all the French members sitting here speak English very well, and that all the English gentlemen understand French most easily, I am persuaded that if Lord Brassey has allowed me to speak so often in either language it was only through his extreme kindness to me, and for my private and personal pleasure.

The President (the Right Hon. Lord Brassey, K.C.B.) : One more pleasant duty remains ; it is that of tendering the acknowledgments of the Institution of Naval Architects to their Secretary, Mr. Holmes. I am sure that you will agree with me in this, that no Institution such as ours has ever had a better Secretary than Mr. Holmes. He is a servant of the Institution of many years' standing. He has often been tried, sometimes tried very hard, but never found wanting. But really the meeting in Paris, so full of difficulties of an unforeseen nature, as it must have been, was an undertaking from which a man less adroit and of a less bold spirit might possibly have shrunk. But there was no timidity about Mr. Holmes in the contemplation of the journey to Paris. He rushed with characteristic eagerness into the undertaking, and I am sure I shall be warranted by the experience of all in bearing my hearty testimony to the admirable success with which Mr. Holmes has discharged his numerous and complicated duties. He is never failing in courtesy, in tact, or in readiness to make every exertion necessary to ensure success. I beg to tender your thanks to Mr. Holmes.

Mr. B. Martell (Vice-President): My Lord and Gentlemen, I have very much pleasure in seconding this resolution. I am sure I only echo your feelings when I say that we all deeply appreciate the very kind words that Lord Brassey has made use of in relation to our Secretary. Those who know anything about the initiation of these meetings, and the work it has entailed upon him, can only value his services to this Institution more and more. He has been most indefatigable. The work has been enormous that has been thrown upon him, and it is only by the great intelligence and the great powers of organisation that he possesses, that he ever could have got through with it in the satisfactory manner he has. His ability as a linguist has also assisted us very much indeed. He is quite an exceptional man for such a service, and it is only such a man as he who could have undertaken such duties as have devolved upon him, with a prospect of success. I need not, I am sure, re-echo the words of his Lordship with regard to his urbanity and kindness, and his desire to assist everyone, not only those belonging to this Institution, but the friends they bring with them, in every possible manner. I am sure you will cordially respond to this resolution, and show your appreciation of the value of our Secretary, and I trust that he will be long spared to this Institution.

Mr. George Holmes (Secretary) : My Lord Brassey, Mr. Martell, and Gentlemen, I am afraid that I am utterly unable to thank you, as I should like to do, for the kindness with which you have received my small efforts on this occasion, and as you always have done during the seventeen years I have had the honour of serving you. Lord Brassey has dilated at some length upon the difficulties which I am supposed to have had to contend with, in preparing for these meetings, but I can assure you that the kindness of our French friends, especially M. Bertin, who has never ceased working on your behalf, and who, during all the time he has been engaged with the examinations of his School of Naval Architecture, has devoted hours every day to me when I was over here, has rendered my task a comparatively light one. I acknowledge that there has been some labour attending it, but I have been so supported and helped by the kindness of all the members, who never gave me any trouble which they could possibly avoid, that it has really been a labour of love to me. It has been said, gentlemen, that prophecy is the most gratuitous form of error ; but last year, on the occasion of our Southampton meetings, I ventured to prophesy that so long as this Institution continued its practice of holding summer meetings at the different out-ports, and in foreign countries, so long would it continue to thrive and prosper. I venture to say that the result of the meetings held in Paris amply proves that that prophecy, at any rate, was not a form of error. I hope that we shall be all spared to work long together, and attend many such meetings in the future. Again, gentlemen, I thank you for your kindness.

PROCEEDINGS IN LONDON.

SPRING MEETINGS OF THE THIRTY-SEVENTH SESSION

OF THE

INSTITUTION OF NAVAL ARCHITECTS.

MARCH 25, 26, AND 27, 1896.

INTRODUCTORY PROCEEDINGS.

The Spring Meetings of this, the Thirty-seventh Session of the Institution of Naval Architects, were held on March 25, 26, and 27, 1896, in the Hall of the Society of Arts, John-street, Adelphi, W.C.

The opening meeting was presided over by the Right Hon. the Earl of Hopetoun, G.C.M.G., President of the Institution, who commenced the proceedings by calling on the Secretary, Mr. George Holmes, to read the report of the Council, which was as follows :—

ANNUAL REPORT OF COUNCIL, 1896.

The Council report with pleasure that the last year has been one of activity and prosperity. The finances of the Institution remain in a satisfactory condition, and the number of members continues to increase.

The Summer of 1895 marked a new departure in the annals of the Institution. For the first time in its history a meeting was held outside the British Isles. As was announced at the last Spring Meetings, a most cordial invitation was received to visit Paris during the Summer. The invitation was accepted, and the Summer Meetings of the Institution were held in the French capital on June 11 to 15, with results which are not likely to be forgotten by those who took part in them. Nothing could exceed the warmth of the welcome, or the splendour of the reception accorded to our members, by the Government of the French Republic, by the Municipal Council of Paris, by the Chamber of Commerce, by the Reception Committee, as well as by the great scientific bodies, private individuals, and manufacturers. Everything that was possible to be done was done to render the visit agreeable and instructive. The Institution was entertained by the President of the French Republic, by the Minister of Marine, by the President of the Municipal Council of Paris, by the President of the Chamber of Commerce, by the Reception Committee, and by our honoured colleague, Monsieur Emile Bertin, who, in his capacity as Chairman of the Executive Committee of the Reception Committee, bore the principal burthen of the preparations for the meetings. The Reception Committee, which was under the honorary presidency of the Minister of Marine, Vice-Admiral Besnard, and under the active presidency of Admiral Charles Duperré, President of the Commission of Works at the French Admiralty, included many of the most eminent naval officers, men of science, manufacturers, merchants, shipowners, and yachtsmen of France, together with representatives of the University of Paris and of the leading technical and scientific Institutions and all the French members of this Institution. Visits were arranged to the laboratory of Monsieur R. Pictet, to the manufactories of Messrs. Cail and of Messieurs Sautter & Harlé, to the Belleville Boiler Works, to the Niclausse Boiler Works, to the locks of the Basin of la Villette, to the Eiffel Tower, and to the drainage system of Paris. In addition, many of the most interesting scientific Institutions and factories in the city and its neighbourhood were open to our members during their stay in Paris.

The most grateful thanks of the Institution are due to the French Government, the Reception Committee, and all the Corporations, firms, and individuals above referred to, for their hospitality and goodwill, and for the successful efforts which they made for the instruction and entertainment of the members who attended the meetings. The thanks of the Institution are also due, in a very marked degree, to his Excellency the Marquis of Dufferin, K.P., who, as Her Majesty's Ambassador in Paris, did all that lay in his power to contribute to the success of the meetings.

The Council have received a most cordial invitation from the President of the Chamber of Commerce of Hamburg, acting on behalf of a committee representing the Government of the city and all its most important corporations, to hold the next Summer Meetings of the Institution in that important port and its neighbourhood. Encouraged by the success of their first visit outside the British Isles, the Council have gladly accepted this most hospitable invitation. They have every reason to know that the utmost efforts are being put forward to make the meetings agreeable and instructive, and they trust that they will be supported by the presence of a large number of the members in doing honour to those who have so kindly invited them. The meetings will be held in the month of June, and full particulars will be published at as early a date as possible.

At the close of the Paris meeting, Lord Brassey, to the great regret of the Council, resigned the office of President of the Institution, as he was about to leave the country to take up the Governorship of Victoria. During the time that he was President, Lord Brassey did all in his power to further the interests of the Institution. His efforts in this direction were invariably attended with success, and his conduct of the Paris Meeting was not only highly advantageous to the Institution, but was deeply appreciated by the French people. Acting under Bye-law 41, the Council elected the Earl of Hopetoun, G.C.M.G., as President of the Institution till the close of the Annual General Meeting, and have now much pleasure in proposing him for election as President by the members. Lord Hopetoun preceded Lord Brassey in the Governorship of Victoria. He is Paymaster-General, and represents the Admiralty in the House of Lords in the present Government. Like his predecessor in the chair, he is well qualified, both by his experience and by the deep interest which he takes in naval matters, to preside over this Institution.

The Council having been approached in reference to the representation of Shipbuilders and Marine Engineers in the technical department of the Board of Trade, and believing that their co-operation in this movement would be in accordance with the best interests of the profession, have appointed Dr. Francis Elgar and Mr. Archibald Denny as their representatives to co-operate with the representatives of other institutions and bodies for the purpose of furthering the object aimed at.

The Council deeply regret to announce the death of one of the Vice-Presidents, the late Dr. Peter Denny, and the resignation, through ill-health, of another Vice-President, Sir James Ramsden. The Institution has also to deplore the death of one of its Members of Council, the late Sir Edward Harland, whose loss will be greatly felt by the whole profession. The death of Captain Le Clerc, Naval Attaché at the French Embassy, and one of our Associates, has caused much sorrow to his many friends in this Institution. His presence, both for his own sake, and as the Naval representative of a friendly Power, was always greatly appreciated at our meetings.

Institution of Naval Architects.

Dr. *Statement of Receipts and Payments for the Year 1895.* Cr.

Receipts.	£	s.	d.	£	s.	d.
To Balance at the Banker's, Dec. 31, 1894	320	17	10			
,, Cash received and paid into the Bank subsequent to Dec. 31, 1894	43	12	5			
,, Balance in Secretary's hand, Dec. 31, 1894	49	11	8½			
				414	1	11½
,, Annual Subscriptions			...	2,178	2	5
,, Life Subscriptions			...	126	0	0
,, Admiralty Grant			...	250	0	0
,, Sales of Volumes			...	206	2	2
				£3,174	6	6½

Payments.	£	s.	d.	£	s.	d.
By Rent	200	0	0			
,, Housekeeper and Cleaning ...	37	14	0			
,, Despatch of Volumes	59	6	9½			
,, Stationery...	18	19	4			
,, Auditors' Fee	5	5	0			
,, Insurance	2	10	0			
,, Postages and Telegrams... ...	57	5	3½			
,, Petty Disbursements	36	15	4½			
,, Bank Charges	1	10	11			
,, Salaries and Wages	869	14	0			
				1,289	0	8½
,, Expenses of Spring Meeting, 1895	29	8	1			
,, ,, Paris Summer Meetings	111	3	9½			
,, Travelling Expenses in connection with meetings...	72	18	6½			
,, Reporting Spring and Summer Meetings	80	0	0			
				293	10	5
,, Advertising	13	9	2			
,, Translating	3	12	0			
,, Gold Medal	12	10	0			
,, Balance for preparation of General Index XXIX. to XXXV....	50	0	0			
,, Printing; Volume XXXVI., Index Volumes XXIX. to XXXV., and Circulars ...	845	5	0			
				924	16	2
,, Balance at Banker's Dec. 31, 1895	653	5	10			
,, In Secretary's hands to meet Current Expenses	13	13	5			
				666	19	3
				£3,174	6	6½

LIBRARY FUND.

Receipts.	£	s.	d.
To Balance at Banker's, December 31, 1894 ...	283	2	0
,, Entrance Fees	201	12	0
,, Dividends on Investments	114	10	1
	£599	4	1

Payments.	£	s.	d.
By Library Expenses	19	3	7
,, Furniture and Repairs	16	13	9
,, Balance at Banker's, December 31, 1895 ...	563	6	9
	£599	4	1

H. MORGAN, Treasurer.
GEORGE HOLMES, Secretary.

We have examined the above-written entries with the books and vouchers, and find them correct.

BALL, BAKER, DEED, CORNISH & Co.,
Chartered Accountants

February 20, 1896.

The following is a List of Donations to the Library :—

"Transactions of the Liverpool Engineering Society," for 1895. *Presented by the Liverpool Engineering Society.*

"Proceedings of the Royal Society," for 1895. *Presented by the Royal Society.*

"Minutes of the Proceedings of the Institution of Civil Engineers," Vols. CXX., CXXI., CXXII., and CXXIII. *Presented by the Institution of Civil Engineers.*

"Subject Index to Volumes LIX. to CXVIII to the Minutes of the Proceedings of the Institution of Civil Engineers." *Presented by the Institution of Civil Engineers.*

"Proceedings of the Institution of Mechanical Engineers," for 1895. *Presented by the Institution of Mechanical Engineers.*

"Journal of the Iron and Steel Institute," for 1895. *Presented by the Iron and Steel Institute.*

"Journal of the Society of Arts," for 1895. *Presented by the Society of Arts.*

"Transactions of the Institution of Engineers and Shipbuilders in Scotland," Vol. XXXVII., 1894-95. *Presented by the Institution of Engineers and Shipbuilders in Scotland.*

"Transactions of the Society of Engineers," for 1895. *Presented by the Society of Engineers.*

"Transactions of the Institute of Marine Engineers for 1895-96." *Presented by the Institute of Marine Engineers.*

"Transactions of the North-East Coast Institution of Engineers and Shipbuilders," Vol. XI., 1894-95. *Presented by the North-East Coast Institution.*

"Transactions of the American Society of Mechanical Engineers," 1895. *Presented by the Council of the American Society of Mechanical Engineers.*

"The Scientific Proceedings of the Royal Society of Dublin," for 1895. *Presented by the Royal Society of Dublin.*

"Journal of the United States Artillery." *Presented by the Editor of the Journal.*

"Transactions of the Junior Engineering Society," Vol. IV., 1894. *Presented by the Junior Engineering Society.*

"Bulletin de l'Association Technique Maritime, Session 1894-5." *Presented by l'Association Technique Maritime.*

"Transactions of the Institution of Mining Engineers," Vols. XXIV. and XXV. *Presented by the Council of the Institution of Mining Engineers.*

"Transactions of the American Society of Naval Architects and Marine Engineers," Vol. III., 1895. *Presented by the American Society of Naval Architects and Marine Engineers.*

"Bulletin de la Société Scientifique et Industrielle de Marseille," 1895. *Presented by the Editor.*

"The Journal of the Franklin Institute," for 1895. *Presented by the Franklin Institute.*

"Proceedings of the United States Naval Institute," for 1895. *Presented by the U.S. Naval Institute.*

"Proceedings of the Royal Society of New South Wales," Vol. XXVIII., 1894. *Presented by the Royal Society of New South Wales.*

"Transactions of the North of England Institute of Mining and Mechanical Engineers," for 1895. *Presented by the North of England Institute.*

"Transactions of the Hull and District Institution of Engineers and Naval Architects," for 1895. *Presented by the Hull and District Institution.*

"Lloyd's Register of British and Foreign Shipping," 1895-96. *Presented by the Committee of Lloyd's Register.*

"Lloyd's Register of Yachts," for 1895-96. *Presented by the Committee of Lloyd's Register.*

"Annual Report of the Royal National Lifeboat Institution," 1895. *Presented by the Royal National Lifeboat Institution.*

"Journal of the Imperial Institute," for 1895. *Presented by the Council of the Imperial Institute.*

"Engineer," for 1895. *Presented by the Proprietors.*

"Engineering," for 1895. *Presented by the Proprietors.*

"Industries and Iron," for 1895. *Presented by the Proprietors.*

"Iron and Coal Trades Review," for 1895. *Presented by the Proprietors.*

"Field," for 1895. *Presented by the Proprietors.*

"Army and Navy Gazette," for 1895. *Presented by the Proprietors.*

"Shipping World," for 1895. *Presented by the Proprietors.*

"Saturday Review," for 1895. *Presented by the Proprietors.*

"Marine Engineer," for 1895. *Presented by the Proprietors.*

"Le Moniteur de la Flotte." *Presented by the Proprietors.*

"Steamship," for 1895. *Presented by the Proprietors.*

"Practical Engineer," for 1895. *Presented by the Proprietors.*

"Machinery Market," for 1895. *Presented by the Proprietors*

"Electrician," for 1895. *Presented by the Proprietors.*

"Arms and Explosives," for 1895. *Presented by the Proprietors.*

"English Mechanic," for 1895. *Presented by the Proprietors.*

"Revue Maritime," for 1895. *Presented by the French Ministry of Marine.*

"Annalen für Gewerbe und Bauwesen," for 1895. *Presented by the Proprietor.*

"Ordnance Notes," for 1895. *Presented by the Ordnance Office, War Department, Washington, D.C., United States.*

"The Naval Annual," 1895. By the Right Hon. Lord BRASSEY, K.C.B., and others. *Presented by the Right Hon.* Lord BRASSEY, K.C.B.

"The Year's Naval Progress," Annual of the Office of Naval Intelligence. *Presented by the Secretary of the United States Navy.*

"The Technology Quarterly and Proceedings of the Society of Arts," 1895. *Presented by the Massachusetts Institute of Technology.*

"Report of Tests of Metals and other Materials made at Watertown Arsenal," for the years ending June 30 1894. *Presented by the Chief of Ordnance, U.S.A.*

"Journal of the Royal United Service Institution." *Presented by the Royal United Service Institution.*

"Attack of a Coast Fortress." *Presented by the Author*, Major ELMSLIE (Gold Medal Prize Essay).

"The Gold Medal Prize Essay of the Royal United Service Institution." *Presented by the Author*, Major F. B. ELMSLIE, R.A.

"Note sur les Nouvelles Écluses du Canal Saint-Denis." *Presented by the Author*, Monsieur MAURICE RENAUD.

"Le Port-Franc de Copenhague." *Presented by the Danish Ministry of Foreign Affairs.*

"Catalogue of the Library of the Institution of Civil Engineers. *Presented by the Institution of Civil Engineers.*

"Carnet de l'Officier de Marine." By LÉON RENARD. *Presented by* Messrs. BERGER LEVRAULT ET CIE.

"Cinematica della Biella Piana." With Plates. *Presented by the Author*, L'Ing. LORENZO ALLIEVE.

"Applied Mechanics." *Presented by the Author*, Professor COTTERILL, F.R.S.

"Bureau Veritas International Register of Shipping, 1894-5-6. *Presented by the Council of the Bureau Veritas International Register of Shipping.*

"Manual of Yacht and Boat Sailing." Eighth Edition. *Presented by the Author*, DIXON KEMP, Esq.

"Catalogue of Naval Books in the Possession of T. J. BENNETT, Esq. *Presented by* T. J. BENNETT, Esq.

"Gleanings from Patent Laws of all Countries." *Presented by the Author*, W. LLOYD WISE, Esq. *Pamphlet.*

"The Steam Engine." *Presented by the Author*, Professor J. H. COTTERILL, F.R.S.

"Nouvelle Méthode de Calcul des Éléments d'une Carène." *Presented by the Author*, Professor A. KRILOFF. *Pamphlet.*

"Le Problème de la Vitesse." *Presented by the Author*, Monsieur J. A. NORMAND. *Pamphlet.*

"La Bataille du Yalu et ses Conséquences dans la Construction des Batiments de Guerre." *Presented by the Author*, Monsieur C. FERRAND. *Pamphlet.*

"Journal of the Western Society of (American) Engineers," Vol. I., No. 1. *Presented by the Western Society of Engineers.*

"Jordan's Tabulated Weights of Iron and Steel." *Presented by the Author.*

"La Marine des Etats-Unis." *Presented by the Author*, Monsieur E. BERTIN.

"Tables of Distances from Port to Port." *Presented by the Author*, C. H. BAILEY.

"Griffin's Electrical Engineer's Price Book," 2nd Edition. *Presented by* CHARLES GRIFFIN, ESQ.

"Yacht Racing Association Rules and Time Allowances for 1896." *Presented by the Yacht Racing Association.*

"Variation de Pas produite sur une Hélice par la Rotation des Ailes dans leur Moyeu." *Presented by the Author*, Monsieur V. DAYMARD. *Pamphlet.*

"Los Origénes de Nuestra Marina." *Presented by the Author*, Admiral LUIS URIBE, Chilian Navy.

The following gentlemen (having been duly recommended by the Council) were unanimously elected Members of this Institution:—Mr. Paul Anselm, of Messrs. James & George Thomson, Glasgow; Mr. Theodore Albrecht, Chief Naval Architect and Technical Manager at the Stabilimento Tecnico Triestino, Trieste; Mr. Frank Barter, of Sir William G. Armstrong & Co., Limited, Newcastle-on Tyne; Mr. R. Bate, Assistant Constructor to the Admiralty; Signor R. Bettini, of the Ministry of Marine, Rome; Mr. J. J. Bourne, Marine Superintendent to Messrs. Green, Holland & Sons, Lime Street Square, London, E.C.; Mr. E. S. Booth, Chief Superintending Engineer to Messrs. Furness, Withy & Co., Limited, London and Boston; Mr. R. W. Booth, Senior Partner in the firm of Messrs. Booth & O'Halloran, Engineers and Shipbuilders, Antwerp; Herr Thomas Bredsdorff, Managing Director of the Flensburg Shipbuilding Company, Flensburg; Mr. J. Bruhn, Surveyor to Lloyd's Register of British and Foreign Shipping, London; Mr. Colin Buchanan, Marine Superintendent of the Indo-China Steam Navigation Company, Shanghai, China; Mr. Arthur Caird, Naval Architect to the firm of Messrs. Caird & Co., Limited, Greenock; Mr. W. H. Carter, Assistant Constructor, third class, Admiralty, Whitehall; Mr. Harry Clarke, Surveyor to Lloyd's Register, Newcastle-on-Tyne; Herr G. W. Claussen, Managing Partner to the firm of Messrs. J. C. Gecklenborg, Geestemunde on the Weser, Germany; Mr. J. W. Collings, Superintendent Engineer and Marine Surveyor for F. Wood, Esq., Steamship Owner, London; Mr. W. R. Cox, Manager to Messrs. Cox & Co., Falmouth; Mr. A. J. Daniels, of the Board of Trade Marine Department, North Shields; Mr. Leslie Denny, Partner in the firm of Messrs. William Denny Bros., Dumbarton; Herr J. A. Drakenberg, Consulting Engineer, Stockholm; Mr. Peter Duff, Managing Director to Messrs. J. Gordon, Alison & Co., Birkenhead; Mr. C. W. B. Dyer, Ship and Engineer Surveyor to Lloyd's Register, Newcastle-on-Tyne; Mr. A. G. Fox, Assistant Constructor at the Admiralty, Whitehall; Mr. Henry Hand, Surveyor to Lloyd's Register of Shipping, Govan, N.B.; Mr. Robert Haig, Surveyor to Lloyd's Register of Shipping, Newcastle-on-Tyne; Mr. B. G. Haynes, Manager to Messrs. Thomas Haynes, Cadiz; Mr. Thomas Hesketh, of the firm of Messrs. Evan Thomas Radcliffe & Co., Cardiff; Mr. W. T. Hockaday, Assistant Constructor in charge of Drawing Office at Her Majesty's Dockyard, Devonport; Mr. J. B. Huddy, formerly Chief Constructor, Her Majesty's Dockyard, Devonport; Signor Francis Jacobitti, Naval Architect in the Royal Italian Navy, Rome; Mr. J. F. Kitching, Superintendent to Messrs. Furness, Withy & Co., West Hartlepool; Mr. Fred Lobnitz, Partner in the firm of Lobnitz & Co., Renfrew, N.B.; Mr. Edward John Milton, Surveyor to Lloyd's Register of British and Foreign Shipping, London, E.C.; Mr. John Daniel Milton, Royal Corps of Naval Constructors, Portsmouth; Mr. Robert Monroe, Manager of the Penarth Shipbuilding and Ship Repairing Company, Limited,

Penarth; Mr. Jas. E. Muir, Consulting Engineer and Marine Surveyor, Glasgow; Mr. John H. Narbeth, Assistant Naval Constructor, first class (act.), Admiralty, Whitehall; Mr. E. A. J. Pearce, Assistant Constructor, second class, Admiralty, Whitehall; Monsieur A. Pierrard, Marine Engineer in Belgian Government Service; Mr. A. C. Ramage, Shipyard Manager to Messrs. Ramage & Ferguson, Limited, Leith; Mr. W. Reavell, Manager of the Marine Department of Messrs. Babcock & Wilcox, Limited, London, E.C.; Mr. Maurice Ritson, Ship and Engineer Surveyor to Lloyd's Register of Shipping, Aberdeen; Mr. Robert Ropner, Junior Member and General Manager of Messrs. Ropner & Son, Stockton-on-Tees; Mr. Leopold Roper, Palace Chambers, Westminster, S.W.; Herr S. F. A. Schnach, Consulting Engineer and Surveyor to the Germanischer Lloyd, Flensburg; Herr F. Schneider, Surveyor to the Bureau Veritas, Hamburg; Mr. Charles de Grave Sells, of Messrs. Maudslay, Son & Field, Limited, Italy; Mr. H. Shand, Superintending Engineer to the Tyne Steam Shipping Company; Mr. G. Simpson, Chief Ship Draughtsman to Messrs. S. White, East Cowes, I.W.; Mr. John Smith, Chief Engineer to the China Mutual Steam Navigation Company, Limited, London, E.C.; Mr. Forster Stephenson, Superintendent Engineer to the African Steamship Company, Liverpool; Herr J. C. Stuelcken, Senior Partner in the firm of Messrs. H. C. Stuelcken & Son, Shipbuilders and Engineers, Hamburg; Mr. R. H. B. Thomson, Partner in the firm of Messrs. Mackie & Thomson, Govan Shipbuilding Yard, Glasgow; Mr. W. C. Wallace, Marine Engineer to Messrs. John Brown & Co., Limited, Sheffield; Mr. T. S. Warren, Ship Surveyor to Lloyd's Register of British and Foreign Shipping, Glasgow; Mr. G. E. E. Warder, First-class Draughtsman at the Admiralty, Whitehall; Mr. Jas. Weir, Partner in the firm of Messrs. G. J. Weir, Engineers, Cathcart; Monsieur Henri Wilkinson, Chief Surveyor to Lloyd's Register of British and Foreign Shipping, Havre; Mr. Jesse Williams, Surveyor to Lloyd's Register of British and Foreign Shipping, Middlesboro'-on-Tees; Mr. Robert Williamson, Surveyor to Lloyd's Register of British and Foreign Shipping, Hull; Mr. J. J. Woodward, Naval Constructor, United States Navy, U.S.A.; Mr. W. Andrew Young, Partner in the firm of Messrs. Lobnitz & Co., Renfrew, Scotland.

The following gentlemen were elected Associates:—The Right Hon. the Earl of Hopetoun, G.C.M.G., Mr. G. L. Bains, Mr. James Bell, Rear-Admiral E. J. Church, Mr. Arthur O. Depree, Mr. E. J. Dove, Mr. M. W. Campbell Hepworth, Mr. L. C. Hope, Mr. A. S. Kettelwell, Captain A. N. Kriloff, I.R.N., Mr. C. Ferd. Laeisz, Professor Carlton J. Lambert, Mr. J. H. Rosenthal, Mr. W. F. Sarjeant, Mr. F. M. Singer, Mr. F. H. Lyell, Mr. John McIntyre, Professor W. H. Watkinson, Mr. J. Clement Wedgwood, Mr. W. E. Wort.

Since the issue of Volume XXXVI., the Institution has sustained the loss of the following gentlemen:—Dr. Peter Denny, Vice-President; Sir E. J. Harland, Bart., Member of Council; Mr. G. A. Calvert, Mr. David Halley, Mr. W. Kilvington, Mr. C. Mitchell, Mr. J. H. Morrison, Lieut. R. A. Napier, Mr. R. Richardson, Mr. John Tipping, Captain A. O. Trijgger, and Mr. E. F. Wailes, Members; Mr. J. Abernethy, Mr. W. Boaz, Mr. F. Holt, Admiral Sir L. T. Jones, Mr. J. D. Lee, Captain Le Clerc, Naval Attaché to the French Embassy; Colonel W. M. Nielson, Mr. John Potter, Mr. John Henderson, Captain F. C. Younghusband, Associates.

The Secretary next read the following list of names of the retiring Members, and the new names nominated by the Council to fill up the vacancies for the Vice-Presidents and for the Ordinary and Associate Members of Council for the ensuing year:—Names proposed for the election of Vice-Presidents: Mr. James Dunn, Mr. John Macfarlane Gray, Mr. John Inglis, and Mr. A. F. Yarrow. Retiring Members of Council:—Sir Raylton Dixon, Mr. James Hamilton, Mr. John Inglis, Mr. H. H.

West, Mr. A. F. Yarrow. New candidates nominated for Members of Council: - Mr. Alexander Adamson, Mr. Sydney Barnaby, Mr. R. R. Bevis, Mr. Theodore Doxford, M.P., Mr. Thomas Soper, Mr. H. G. Spence, Mr. G. Stanbury. Retiring Associate Members of Council:—Professor J. H. Cotterill, F.R.S., Vice-Admiral Digby Morant. New candidates nominated for Associate Members of Council:—Rear-Admiral C. C. P. FitzGerald, and Captain S. Eardley-Wilmot, R.N.

The President (the Right Hon. the Earl of Hopetoun, G.C.M.G.) next put to the Meeting the following list containing the names of the President, Vice-Presidents, and Treasurer for the ensuing year, which was unanimously adopted:—President—the Right Hon. the Earl of Hopetoun, G.C.M.G. Past Presidents—the Right Hon. the Earl of Ravensworth; the Right Hon. Lord Brassey, K.C.B., D.C.L. Vice-Presidents—H.R.H. Duke Alfred of Saxe-Coburg and Gotha, K.G., K.T., K.P., G.C.B., G.C.S.I., G.C.M.G., G.C.I.E., Admiral of the Fleet; the Right Hon. the Earl of Northbrook, G.C.S.I.; the Right Hon. the Earl of Ravensworth; the Right Hon. Earl Spencer, K.G.; the Right Hon. Lord Armstrong, C.B., D.C.L., F.R.S.; the Right Hon. Lord George Hamilton, M.P.; the Right Hon. Lord John Hay, G.C.B., Admiral of the Fleet; the Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S., Admiral; Sir Nathaniel Barnaby, K.C.B.; Sir Frederick Bramwell, Bart., D.C.L., F.R.S.; Sir Alexander Milne, Bart., G.C.B., Admiral of the Fleet; Sir Frederick W. E. Nicolson, Bart., C.B., Admiral; Sir Edward J. Reed, K.C.B., F.R.S.; Sir W. H. White, K.C.B., LL.D., F.R.S.; Sir James Wright, C.B.; F. K. Barnes, Esq.; F. Elgar, Esq., LL.D., F.R.S.; Benjamin Martell, Esq.; Henry Morgan, Esq. (Treasurer); George W. Rendel, Esq.; J. I. Thornycroft, Esq., F.R.S. W. H. Tindall, Esq.

The President then nominated Mr. J. T. Milton, Member of Council, and Mr. H. A. B. Cole, Member, as Scrutineers to examine the voting papers.

The President (the Right Hon. the Earl of Hopetoun, G.C.M.G.) then proceeded to deliver the following Opening Address:—I am glad to be able to congratulate the Institution upon the eminently satisfactory nature of the Report which has just been presented by the Council. It is a prosperity Report, I think, in every sense of the word, and the meeting has heard with pleasure, I feel sure, that during the past year there has been no falling off in either the activity or sound financial position of the Society.

The events of last June must be fresh in the minds of all those whom I am now addressing. The Institution will ever bear in grateful recollection the warm invitation extended to them to visit Paris. The hearty welcome accorded to those who were able to attend, and the untiring and successful effortsof our hosts to make the visit a pleasant and instructive one, has placed a heavy load of debt upon this Institution.

We are glad to welcome amongst us to-day some of those gentlemen to whom we owe so much, and they may rest assured that we, on our side, will strive to repay a portion of the debt due to them during their sojourn on this side of the water.

We must not forget, when thanking our hosts of last year, that we are about to incur fresh liabilities in another direction. The Institution has, as the Report tells us, been invited to hold its meetings during the coming summer in that great centre of industry and commercial enterprise, the city of Hamburg. My own personal feeling is that we can best testify our appreciation of this hospitable compliment by attending in as large numbers as possible, and I am absolutely certain that we may look forward to a most enjoyable visit over the water.

I pass now to the concluding paragraph of the Report, which must of necessity tinge the whole document with a certain tone of sadness. The removal from our ranks by death of Mr. Peter Denny and Sir Edward Harland must be a serious loss to the Institution. They were gentlemen in the front rank of their profession. Their expert knowledge and experience were of the utmost value to those associated with them in this Society, and their loss causes a serious void amongst those who are left. We feel, too, very keenly the loss by death of Captain Le Clerc, the late Naval Attaché at the French Embassy. He was deservedly popular with all who knew him, and was nowhere more deeply appreciated than by his brother members in this Institution.

I cannot, gentlemen, turn from the subjects contained in the Report without some reference to the severe loss which the Institution has sustained in the removal to another sphere of usefulness of the late President, Lord Brassey. It would not be possible, on an occasion such as this, to do justice to the services which he has rendered to the Royal and Mercantile Navies of this country. An expert himself in all save the most technical details of the marine profession, he has done more than any other man to make our Navy, and the necessity for a Navy, familiar to the public. Before he commenced the publication of his Annual it was well-nigh impossible for the ordinary individual to obtain any continuity of information upon this subject. Lord Brassey has placed this information within the reach of everyone, and the taxpayer of to-day has only himself to blame if he does not acquire a full knowledge of this all-important question. Lord Brassey's boundless hospitality, his warm heart, and his untiring energy will be greatly missed here, but, believe me, they are fully appreciated by those amongst whom he is now living.

The only fault that I can see in Lord Brassey—my only complaint against him—is the fact that he has made the position of President of this Institution a very difficult one for his successor to fill. When I was first offered this post, I felt very diffident about accepting it. I felt strongly that there are many others, whose experience and training fit them so much better than mine fits me to undertake the duties connected with this position; but the knowledge that I should be brought in contact with the leading experts of that profession which has so greatly tended to make our Empire what it is, that I should be privileged to hear them discuss subjects which have been of engrossing interest to me since I was a boy, was too strong a temptation for me to resist. I yielded to this temptation, and I can only now hope that I may justify your choice, and discharge the duties entrusted to me to your satisfaction and to my own.

It is now my duty to briefly allude to the chief events in the shipbuilding line which have taken place during the past year, or are taking place at the present time. The most striking event of the moment, and the one which must be foremost in our minds just now, is the programme of construction just made public by the Admiralty. As you are aware, five new battleships are to be laid down: they are to be improved "*Renowns*," their displacement is to be 12,900 tons. In offensive power, they will be equal to the *Majestic* class; in speed and radius of action they are designed to have a slight advantage over that class, although their displacement will be some 2,000 tons less. Some apology would be due from me for giving these figures, which must already be so familiar to you, were it not that they recall to my mind a very important point in the speech which your former President—Lord Brassey—delivered to you last year. He said, speaking of the *Majestic* class: "While fully recognising the superiority of the latest battleships, in a new programme it may not be superfluous to set forth the leading arguments in favour of keeping down dimensions, and distributing the fighting power of the fleet in a greater number of ships;" and again: "As the ten ships now

building are of the largest dimensions yet reached in naval architecture for war, our next batch of ten ships might well be of the type represented so admirably by the *Renown*." I quote these words of Lord Brassey with the utmost respect, and it would seem at first sight as though the designs of these new ships, which we are about to build, were in some degree a concession to the views of those who advocate moderate dimension (a very elastic phrase) in our ships of war; but in my opinion they are a very direct and very excellent answer to those who favour a policy of building smaller ships than has been our wont of late. It is true that they are smaller by the size of a third-class cruiser than are the *Majestics*, but it has been necessary to make some sacrifices to attain this diminution of size. As far as I can learn, there is practically a consensus of opinion amongst naval experts, as also amongst our foreign critics, that the ships of the *Majestic* class embody in the highest degree all that is most desirable in a British battleship; but people will say, if this is so, why not continue to build *Majestics?* No doubt we should do so, if the *Majestics* were suited to all of the multifarious duties which the British Navy has to perform. Events, however, over which we have no control, and the development of maritime powers which a few years ago were non-existent, have made it possible that our Navy may be called upon to act in waters unsuited to the great draught of the ships of the *Majestic* class. For these reasons it has been found necessary to design the new vessels with two feet less draught than the class I have mentioned, and with a displacement of 2,000 tons less.

The four great requirements in a battleship are, without doubt, speed, radius of action, gun power, and defensive armour. History teaches us the importance which our forefathers attached to the weather-gauge. It was regarded by them as all-important to that fleet which hoped to assume the offensive; the weather-gauge of to-day is the power to out-steam the fleet of the enemy, the power to concentrate quickly, and bring on a general action at the most favourable moment. Coal supply, as limiting radius of action, is also of vital importance to the fleet which must keep at sea, and which must carry on operations at a great distance from its base. The gun power of these ships leaves nothing to be desired, as it equals that of their larger consorts. We now come to the price paid for the 2,000 tons of displacement taken out of these new ships. It is a sacrifice of about 25 per cent. of defensive armour. The development of the quick-firing gun and of high explosives makes it essential that the guns of the secondary armament and their crews should be properly protected; and it has, therefore, been decided to make the reduction in the side armour, which is to be of 6 in. instead of 9 in., as in the *Majestic* class. This, then, is the sacrifice which our designers have had to make, and it is considered to be the least harmful sacrifice that could be made under the circumstances. I must not forget to mention, too, that these battleships will be the first that our Admiralty have fitted with water-tube boilers.

I now pass to the cruisers projected in the new programme, and here I feel myself in closer accord with those who advocate moderate dimensions; but, again—What are moderate dimensions? Ten years ago a cruiser of 10,000 tons would have been a monster. To-day it comes under the heading of moderate dimensions. The new cruisers are of 11,000 tons displacement—that is, about mid-way between the *Blenheims*, of 9,000 tons, and the *Powerfuls*, of 14,000 tons. This excess of 2,000 tons over the *Blenheim* class would seem to be devoted to the attainment of a higher continuous sea speed, a more perfect system of protection to the guns and ammunition supply, and to the sheathing and coppering of the ships' bottoms, in order that they may be able to keep the sea for a longer period without docking. The considerable offensive-power which these vessels possess would enable them to cope with anything afloat, save a modern battleship; and their great speed would enable them to avoid a conflict with an enemy superior to themselves. They should prove equal to

making quick passages in heavy weather, and altogether they promise to be useful adjuncts to a fleet of heavy ships. I am quite aware that the wisdom of building these large and expensive cruisers without side armour at the water-line has been called into question, but I hardly think that this is a fitting moment to discuss such a subject. After careful consideration, after exhaustive experiments, and after availing themselves of the best expert advice at their disposal, the Admiralty have, for some time past, deliberately elected to discard side armour in all our cruisers, and to rely on armoured decks and coal protection.

In our new second-class cruisers we again find an example of the upward te dency of moderate dimensions. They are vessels of 5,600 tons, which is the precise size of the *Orlando* class—the belted first-class cruisers of ten years ago.

The Admiralty have also the intention of building a large number of third-class cruisers of the *Pelorus* type, vessels of 2,135 tons displacement, and with a speed of 20 knots. Although, on the whole, their design has been approved of, it has been urged that they should have greater length, in order to improve their coal endurance. I would point out that, as matters stand, they will be 20 ft. longer than their prototypes—the *Bellona* class—and that their radius of action at 10 knots speed is calculated at 6,000 miles, which may be considered entirely satisfactory for cruisers of their size, being twice that of the *Bellonas*. They have also a higher freeboard, and so will be better sea-keeping vessels than the *Bellona*, and will carry a more powerful armament.

Any reference to the work in hand for the Royal Navy would be imperfect without a short notice concerning the torpedo-boat destroyers built or building in private yards for the Admiralty. They are the greatest novelty of our time, and each batch of these little vessels, when completed by the contractors, appears an improvement upon the last batch. To obtain a speed of thirty knots, or thereabouts, is such a marvellous achievement that, the firms which have succeeded in accomplishing this feat deserve the highest credit, and the grateful thanks of the country.

Frankly, gentlemen, if we are to keep our place among the nations of the world, if our Navy is to continue in the future to be the prop and stay to us which it has been in the past, we must assure ourselves that our ships shall always be, individually, and class for class, larger, better, faster, and more powerful than those of foreign countries.

In speaking of the work which has been done in connection with the Royal Navy during the past year, I cannot help referring to the extraordinary rapidity with which Her Majesty's first-class battleships *Majestic* and *Magnificent* have been built and fitted for sea. These ships, as you know, were completed within two years of the date of their being laid down—a wonderful feat on the part of the Dockyard staff both at Portsmouth and Chatham. As I have already ventured to point out, these ships have won the entire approval of all naval officers, and they have exactly fulfilled the anticipations of their designer, Sir William White, who is about, I am glad to say, to return to his work, restored to health after his long and serious illness, and I most heartily congratulate him and the distinguished profession to which he belongs upon this fact. Fifty-nine ships of war, with a total displacement of 148,000 tons, were launched in 1895; of these fifty-one were built in private establishments and eight in the Royal Dockyards. These figures, of course, include warships built for foreign Governments.

I do not think that there are any special features to chronicle in connection with the development of the Mercantile Marine during the past year; 528 steamers, with an aggregate tonnage of 905,000 tons, and 53 sailing vessels, with a tonnage of 46,000 tons, constitute the output of the yards of the United Kingdom.

Three points are apt to strike one when studying the development of the Merchant Navy; the steady increase of steam tonnage and the equally steady decrease of sailing tonnage, the substitution to a greater extent each year of steel in place of iron as the material used for construction, and the greatly enlarged size of cargo steamers.

The net increase during the past year in the tonnage of the world for Mercantile purposes amounts to about 518,000 tons.

Turning to the programme of the proceedings of our present Session, I venture to think that it bids fair to be a very interesting one.

Two papers upon the subject of water-tight doors in warships are to be read, one by Lord Charles Beresford, and the other by Colonel Soliani, Director of Naval Construction, Royal Italian Navy. I think that nothing could better illustrate the advantage of an Institution of this sort than the facility which it gives for an interchange of ideas between those who design the ships and those who have to use them.

Mr. Seaton's paper on the use of the microscope for revealing the causes of mysterious fractures in steel, proves to us that the engineers of the present day fully recognise the necessity of availing themselves of all the resources of science in improving their practice. The information gained from a study of this subject must be of great practical advantage, and we may hope that ere long railway accidents, such as the one which happened to the Great Northern express at St. Neots some few months ago, and which was directly traced to the breaking of a rail, may be rendered impossible, and many valuable lives saved.

There are no less than three papers down on our programme which deal with the question of water-tube boilers, a most important one at the present time.

While the programme thus contains many papers of great practical importance, the theoretical side of naval architecture has not been neglected. Mr. R. E. Froude follows up a subject with which his father's name is closely identified, by giving a paper upon the rolling of ships. A Russian gentleman, Captain Kriloff, contributes a paper on the kindred subject of the pitching of ships, and from Mr. Bruhn we welcome an able paper on the ever-interesting subject of stability. The numerous losses of grain-laden vessels in the past have called forth a paper from Mr. George Little, which, it may be hoped, will draw attention to the subject.

In concluding, gentlemen, I must ask you to forgive me if my address has not appeared to you worthy of so important an occasion, if the ideas which I have ventured to place before you have seemed crude and half-formed. It only remains for me to remind you of the difficulties which confront a layman when addressing an audience composed of experts, and to thank you in no formal sense, but in all sincerity, for the kind and patient hearing which you have given me.

RESULT OF THE BALLOT FOR THE ELECTION OF VICE-PRESIDENTS, MEMBERS, AND ASSOCIATE MEMBERS OF COUNCIL.

After the reading of Colonel N. Soliani's paper on Wednesday, March 25, the Scrutineers appointed to examine the ballot papers for the election of the new Council presented the following report:—

Society of Arts, John Street, Adelphi, London, W.C.,
March 25, 1896.

To the Right Hon. the EARL OF HOPETOUN, G.C.M.G., *President, Institution of Naval Architects.*

MY LORD,—Having examined the voting papers for the election of two Vice-Presidents, six Members of Council, and two Associate Members of Council, we beg to report that the following gentlemen have been duly elected:—

As Vice-Presidents—

Mr. James Dunn.	Mr. A. F. Yarrow.

As Members of Council—

Mr. A. F. Yarrow.	Mr. James Hamilton.
Mr. John Inglis.	Mr. H. H. West.
Sir Raylton Dixon.	Mr. G. Stanbury.

As Associate Members of Council—

Professor J. H. Cotterill.	Vice-Admiral G. D. Morant.

As the election of Messrs. Dunn and Yarrow to be Vice-Presidents creates two vacancies for Members of Council,

Mr. T. Soper and Mr. W. Theodore Doxford, M.P.,

are entitled to be elected to these vacancies.

We are,

Your obedient servants,

(Signed) J. T. MILTON, Member of Council,
H. A. B. COLE, Member,
(Scrutineers).

WATER-TIGHT DOORS, AND THEIR DANGER TO MODERN FIGHTING SHIPS.

By Captain the Right Hon. Lord Charles Beresford, C.B., R.N.

[Read at the Thirty-seventh Session of the Institution of Naval Architects, March 25, 1896; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

The country is now thoroughly aroused to the fact that the punctual and certain delivery of our food and commerce, and even the existence of our Empire, depend absolutely on our command of the sea. Hostilities may be commenced by an attack upon weak points by torpedo fleets, by mining fairways, by the attempted destruction or interruption of commerce by cruisers or torpedo-boats, or even, indeed, by the levying of indemnities upon undefended towns; but whatever the result of these preliminary efforts, the ultimate issue of a naval campaign must depend upon the defeat or success of the battleship fleets. It therefore becomes imperative that nothing, which human foresight can conceive, should be left undone to ensure that the individual ships of the battleship fleet will resist as long as possible the three modern elements of danger to be faced in action, *i.e.*, the gun, the torpedo, and the ram; and also those unforeseen contingencies inseparable from the life of a fighting ship, whether in peace or war.

It appears to me that every effort has been made, as far as human ingenuity has gone at present, to secure a ship floating after a severe gun action, but equal attention has not, in my opinion, been paid to this consideration in the event of a ship being badly wounded by ram or torpedo. It is to reduce the probability of losing a vessel through the agency of these "elements" that I make the following proposals.

A battleship is a variety of compromises, and water-tight doors form one of those compromises. The water-tight door compromise may be defined in the following manner:—It is the safety of the ship *v.* the convenience of the departments. In my opinion the safety of the whole ship is infinitely more important than the convenience of the different departments. According to the system which obtains at present we put ourselves to great trouble, inconvenience, and expense, and add enormously to the weight of our ships (a most material point) by building a large number of bulkheads athwartships, and fore and aft, to ensure her safety when wounded below the water-

line. Then, in order to defeat our original object, we cut a great hole (often two) in each bulkhead for the convenience of the different departments on board, and so practically reconvert the ship into one compartment. It has so often been proved that the holes are invariably open when an unforeseen contingency occurs.

I am well aware that this matter has been one of continual debate and discussion amongst the separate departments, the seaman, the constructor, and the engineer, who have to use their expert knowledge in deciding the many complex and tremendously difficult problems involved in the construction of a battleship. I am therefore somewhat diffident about putting forward my idea in the face of the expressed opinion of the constituted authorities, who have devoted their energies to the consideration of this matter; but, having for some years given this subject my earnest attention, and knowing the opinion of a very large number of my brother officers, as well as constructors and engineers outside the Service, I have come to the conclusion that there is a great diversity of views on the water-tight door question. In view of this diversity of opinion, and the fact that the French have almost entirely done away with water-tight doors in their new ships, I venture to lay my arguments in favour of a reduction in the number of water-tight doors before the highest community of experts, on such a matter, that the country can produce.

It is a fact that upon the loyalty of water-tight doors when closed, and upon the assurance that they *are* properly closed, depends the power of a battleship to float when wounded by ram, torpedo, or possibly the gun. In war time our ships will not always be in action, but they will nevertheless be exposed to dangers (principally of submarine explosions) which may be totally unlooked for, and in the nature of a complete surprise.

Although all water-tight doors would be closed on going into action, it is possible, indeed probable, that all, or many of these might be open for ventilation or convenience, when one of the unlooked for contingencies I have suggested occurred. It has been authoritatively stated, for instance, that the cause of the loss of the *Victoria* was that the water-tight doors were not closed, and it has been constantly proved to be impossible to close water-tight doors in an emergency, no matter how well disciplined, and how gallant the ship's company may be. The splendid, but unavailing heroism of the officers and men of the *Victoria* was a shocking and terribly convincing proof. Other evidence exists, namely, *Re d'Italia* ramming at Lissa, *Vanguard* and *Grosser Kurfürst* sunk by collision in peace time during manœuvres, and *Blanco Encalada* sunk by torpedo. It was reported in each case that, had it been possible to close the doors in time, the ships would have been saved. I believe it to be a fact that no ship has been saved when wounded below water-level at a moment when her water-tight doors were open. If doors be open in an unforeseen contingency, or when the ship is rammed

or torpedoed, it is allowed that the ship is in danger. The possibility is that her doors may be open. Hence the danger of having the doors at all.

I propose to avoid the danger of that possibility by (1) doing away altogether with a number of the doors, and (2) by so modifying the size and position in bulkhead of some of those which remain, as to prevent a sudden rush of water being immediately distributed through different compartments in the ship, as occurred in the *Victoria*.

The total number of doors in each of the following ships is:—*Magnificent*, with 150 compartments, 208 doors; *Royal Sovereign* and *Repulse*, 187 compartments with 148 doors; *Rodney* and *Anson*, 121 compartments and 98 doors; *Theseus* and *Hawke*, 122 compartments and 98 doors; and the *Agincourt*, 29 compartments and 17 doors. The old ships have few compartments, but much fewer doors in proportion.

The following list gives the number of doors in ships of the *Magnificent* class dealt with according to my suggestions:—(1) Doors I propose should be done away with, 19; (2) doors I suggest should be modified in accordance with my proposals, 23; excepting ammunition passage doors and (3) doors in which no alteration is proposed, 166. Many of these doors are bunker doors, and others on main deck, and places where they are easily closed.

(1) By far the most important doors to do away with, in my opinion, are all on all decks below water-line between 63 and 105 stations—which bulkheads enclose the engine-room and boiler-room compartments. I agree that quick communication is necessary between the engineer officer and his subordinates, but quick verbal communication is all that is required; and, in my opinion, all demands could be met by a small scuttle. These compartments form the belly of the ship—the great floating power from which she gets her buoyancy. In case of one of them being flooded with water, or filled with steam from a fractured pipe, or other cause, the water or steam is immediately communicated to the whole belly of the ship owing to the impracticability of closing the water-tight doors in an emergency—as shown by the examples quoted. Now, not only is each thwartship bulkhead pierced by a door (often two), but the midship bulkhead also has often two in each compartment. The next most important place is, in my opinion, right forward, where water-tight doors should be done away with altogether in the collision bulkhead, and I think they should also be done away with in the next bulkhead abaft, in order to be still comparatively safe if the collision bulkhead gives way. In fact, no opening whatever, either sluice valve or anything else, should exist in this bulkhead. The only way to get to the foremost compartment should be by a manhole in the deck above.

Incidentally it might be mentioned that I think (1) it would be advisable to shift the collision bulkhead further aft, so that it should be quite clear of all the strengthening pieces supporting the ram; (2) that it should be far more strongly fitted

than it is ; and (3) that it should be rounded like a barbette instead of being at right angles to the side.

(2) In the case of the doors I propose to modify, the large doors should be replaced by small rectangular openings close up to the deck, at the top of the bulkhead, as shown in sketch (Plate XXVII). This proposal is intended to allow officers and men to get from one compartment to another quickly if necessary. The merit I claim for this fitting may be exemplified in the following manner :—If a ship be wounded by torpedo or ram in a compartment below the water-line, the water will rush in with irresistible violence. With the present system of water-tight doors, where the sill is nearly level with the deck, there is nothing to prevent the water rushing to all parts of the ship at once, and it becomes impossible to close the doors.

With my proposal the water meets a solid bulkhead all round the compartment to a height of five, six, or more feet, according to the height of compartments. The water is confined for some appreciable time in one space, and this gives ample time to close and secure the " rectangular opening " at the top of the bulkhead.

Another point of advantage I claim for this suggestion is that bulkheads having small openings in them must, on the face of it, be stronger than bulkheads having large doors, reaching for nearly their whole length, from deck to deck. In the event of a ship being rammed, the violent blow will not only disturb bulkheads locally, but is certain to disturb bulkheads at some distance from the point of impact. Bulkheads with small openings, as proposed, are certain to withstand the shock better than bulkheads having large apertures as at present.

If a ship be wounded by torpedo, or ram, in a compartment above and near the water-line (so that water can enter), the utility of my proposal is equally great, as the solid bulkhead will confine the water to one locality. Even were the water-tight doors closed in battleships, I have no faith in the strength of the fore-and-aft bulkhead in engine and boiler rooms. Even when strengthened by Z-angle irons, as has been done lately, it is not strong enough ; and the test for this bulkhead should, in my opinion, be far more stringent than that now employed, *i.e.*, being pumped on with a hose.

(3) In the case of the doors in which no alteration is proposed, they are necessary for the fighting efficiency of the ship, as there are certain places where doors are indispensable (such as for the supply of ammunition), and in bulkheads of compartments that have no ladderway or escape through deck overhead. It is no use arming ships with quick-firing guns unless the line of communication from the magazines to the guns allows for constant supply and quick delivery ; besides which men are berthed and messed in most of the localities where no alteration is proposed, and therefore doors are more likely to be quickly and efficiently secured than in places where men

have to go down below to close and secure a door where water may be rushing in on top of them.

There are only seven doors in the whole ship below the water-line that, in my opinion, should remain. The doors that are necessary should, I think, be improved. I cannot conceive a worse principle than is employed for closing the hinged doors in the British Navy. The hanks and butterfly nuts have each one to be secured or screwed up separately. The consequence is that in a panic, or sudden emergency, you invite an accident, as it is unlikely that men will remain to secure each hank and each butterfly nut, without which the door cannot be effective. I have seen many doors, a great deal better than the ones employed in the Navy, of the same weight and about the same price. The principle that should be enforced is that it should be possible to shut the door and secure it in one movement.

Owing to the length of my paper, I do not propose to enter into details concerning the doors of the other classes of ships I have named; but I am most strongly of opinion that, in fighting ships of all classes the suggestions I have made should be carried out in each shipbuilding, and that ships built should be altered in the direction I advocate. It is only by using foresight that possible, and I consider probable, dangers may be avoided.

In the very latest class of ship building (*Terrible*) we appear to have gone more mad on water-tight doors than in any other class. The engines and boilers in the belly of the ship are in ten different compartments, and in these ten different compartments there are sixteen doors; a system of construction that appears to me to be simply risking the safety of the ship, by preventing the bulkhead from carrying out the object of its existence.

It will be argued that, owing to the excellence of our drill and discipline it is possible, from constant practice, to close these doors in time to save the ship after an accident has occurred. I entirely disagree with this, and have given proofs that it cannot be done. The system of closing doors by evolution as to time invites an accident. As all captains well know, the men will run down, if allowed, heave one or two hanks over a vertical door, or let fall a horizontal door without screwing up all butterflies and report it closed, which is true, but the door is not properly secured. If the water got the wrong side of the bulkhead or deck, the door would immediately burst open. The argument that my proposals will affect the ventilation of the ship cannot be sustained in these days of mechanical ingenuity for overcoming difficulties.

Lately—within a few weeks—I paid a visit to Toulon, and was greatly struck to find that the two new French ships, *Carnot* and *Jauréguibery*, building there, have been constructed, so far as the water-tight door question goes, almost exactly as I have

advocated for some years. These ships have not one single compartment that goes right across the ship.

Their six boiler and two engine rooms are entirely cut off from any communication with each other, except by voice tube. The only ingress or egress is by small rectangular openings, at the top of the bulkheads, and level with top of boiler in boiler-room, and top of cylinder in engine-room. To get from one to another it is necessary to go up a ladder, cross a deck, and then descend again. Even their submerged tubes are in separate water-tight rooms with solid bulkheads, instead of both being in one great space with doors in it, according to the English custom.

Moreover, the fore-and-aft bulkheads are far more strongly secured than ours. Every three feet there is a heavy H iron (like a railway rail) bolted vertically to bulkheads. They have also the same principle in use, with regard to small openings in bulkheads above the water-line, as I advocate. These openings are oval, and on the top of a coaming about 4½ ft. high. It is necessary to put one foot through and then your bent head, to get from one compartment to another.

The French ships, owing to the disposition of their weights, are not so stable as our ships, and it may therefore be argued that, with this knowledge, they divide their ships into smaller and more numerous compartments. But, though our ships may be more stable, I prefer to localise the water as much as possible when it does enter through the effect of a wound.

I most earnestly commend to the attention of the Institution of Naval Architects the views I have enunciated in this paper. I maintain that with such practical facts as the *Victoria's* loss staring us in the face, we are quite wrong to continue the system of water-tight doors at present adopted in our Navy, particularly in the case of battle-ships.

The battleship fleet, upon which we most rely, consists of only twenty-two ships (I speak of the modern ships), out of which seven cannot be ready for the pennant for a year or more. I do not count the twelve light-ended ships, as I consider if they get into "close action" they will go down bottom up after the first twenty minutes; and I do not count the fourteen battleships armed with muzzle-loading guns, as there is no place you could put them in an action where they would have a chance, even against small cruisers, armed with modern breech-loading quick firers, as the small cruiser has not only the advantage of speed, but of range as well. Therefore, do let us be perfectly certain that there is, as far as human foresight goes, no weak point in those ships upon which we do depend, and which should have the power to keep afloat under almost any contingency.

Summary.

The summary of my contentions is :—

(1) Many water-tight doors can be abolished. This would add to the safety of the ship.

(2) Many water-tight doors can be modified with the same advantage.

(3) That where water-tight doors are necessary of the present size, they should be constructed on a better principle than those we now use.

(4) That all these alterations in construction can be carried out without affecting the fighting efficiency of the ship.

My object in writing this paper is to invite discussion from those shipbuilding experts who are best able, by argument, to prove that those who agree with me on this all-important question, are right or wrong.

WATER-TIGHT DOORS.

By Colonel N. Soliani, Director of Naval Construction, Royal Italian Navy; Member.

[Read at the Thirty-seventh Session of the Institution of Naval Architects, March 25, 1896; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

The subject of water-tight bulkheads, in relation to the safety of ships, has been fully dealt with in various valuable papers read before this Institution; but, as far as I am aware, not sufficient importance has been given to water-tight doors, on the efficiency of which so much of the efficiency of the bulkheads themselves depends.

That things in this matter are not satisfactory is made apparent, not only by sad disasters, but by the general opinion that a water-tight bulkhead, to be really efficient, ought to have no water-tight doors whatever. Of course much of this feeling is due to daily experience, showing that the human factor is not always to be relied upon. And, of course, strong and perfect bulkheads and water-tight doors are of no use when the latter are neglected, or left open unnecessarily, or when no sufficient drill is practised on board to secure their being shut quickly when needed. But, apart from this, a good deal of distrust is still due to the doors not being always made in the best way to secure promptness of action and efficiency. The scope of this paper is to pass in review the various systems of water-tight doors adopted, and to draw from them the requisites which the latter ought to satisfy to secure the best practical results in the conditions of service under which they are to act. It is at sea that these conditions principally manifest themselves, and it is specially at sea that danger exists and the functions of water-tight doors have occasion to and must be exerted in the most efficient way.

In respect to the said conditions, water-tight doors may be divided into three classes:—

(*a*) Water-tight doors, at or below water-line, which, in a sea-way, can be kept always completely shut, or only occasionally and for a short time open, after which the doors can be restored to their closed position. Water-tight doors well above water-line.

(*b*) Water-tight doors below water-line, between compartments, such as the engines and boiler-room compartments, through which communication, when the ship is at sea, is permanent or practically so.

(*c*) Bunker water-tight doors, which not only are to be kept open in a sea-way, but are also liable to be jammed by coal when closing.

Hinged Water-tight Doors.

Water-tight doors under head (*a*) do not require to close quickly, and therefore are usually made hinged, in which form a good, simple, light, and efficient water-tight door can be obtained.

Figs. 1, 2, and 3, Plate XXVIII, show how these doors are generally made. The hinged door has, all round its edge, screw or lever latches to keep the door, when shut, quite tight against the seat frame. For bunkers above protective decks screw latches are preferred, all independent and worked only from one side, as in Fig. 1. The seat frame is generally fitted with indiarubber or tuck packing, but when absolute tightness is not necessary, as is the case with coal bunker bulkheads above protective decks, or with doors high above water-line, the packing can be dispensed with, the seat being then a simple solid frame of rectangular section, as shown in Fig. 2.

These solid frames, while efficient, are economical, as they dispense with the packing, which is expensive and subject to rapid deterioration. Various packings, other than indiarubber or tuck packings, such as cotton packing in a natural condition or well greased, leather, &c., have been tried; but, so far, none of them has yet been found to combine durability, efficiency, and cheapness in the desired degree.

Doors in passages through bulkheads have lever latches workable from both sides, as in Figs. 2 and 3. These latches, when the doors are well above water-line—as passage doors on main decks—may be fitted only along the edge opposite to the hinges, and connected all to one handle, in which way they can be worked together at one time (Fig. 2).

Latchless doors have also been resorted to. In this case they are double, viz., they have two shutters working opposite one another on the two sides of the bulkhead; so that, whichever side is flooded, there is always one of the two shutters pressed close by the pressure of the water itself. Suitable springs cause both shutters to close when released after having been opened. These doors are said to be handy and efficient.

Sliding Water-tight Doors.

Water-tight doors under head (*b*) require efficiency and quickness combined. Therefore, they are usually made of the sliding form, and workable both from the door itself and from the decks above.

They are made to slide vertically or horizontally, according to the space available; but vertical sliding is preferred, when possible, as the door can be made comparatively simpler and lighter. Some people are of opinion that vertical sliding is also preferable, as being faster when closing, but, with proper arrangement, horizontal sliding need not be inferior in this respect, while certainly it offers greater easiness of manœuvring when opening. This point is worth consideration, and will be dealt with more fully later on.

When horizontal, the doors slide on running wheels, by which they can be worked rapidly, both when opening and closing, without being liable to jam, as is the case when they slide on the guides.

The wheels are fitted in such a way as to be accessible for inspection and repair.

Horizontal sliding doors are generally worked by a rack and pinion gear, the rack being fitted to the door, and the pinion to a vertical shaft leading to the main deck above. A hand key, which is kept always ready near, or on the door itself, can be quickly geared on the pinion and used as a handle to work the door from its place. In this way the door can be opened and closed easily by the same person who wants to pass through it—an advantage which is not secured with vertical sliding doors, except by special arrangements.

Fig. 4, Plate XXVIII., shows an ordinary horizontal sliding door, as usually fitted on board ships.

The lower side of the door frames of sliding doors, when grooved to form a guide to the shutter, is liable to get choked with dirt, and to prevent this the guide is usually covered with a lid, which opens automatically when the door is closed. To avoid the necessity of this cover, the lower side has generally no guide.

If we turn a horizontal sliding door 90° on its plan, we have a vertical sliding door needing no alteration for its working. However, with vertical sliding, the gear, instead of a rack and pinion, is generally a fixed vertical screw shaft working in a nut attached to the door (Fig. 5, Plate XXIX.). With this arrangement the movement of the door is slow, both when opening and closing. Such slowness is not convenient, specially when closing, which operation, in time of emergency, ought to be as quick as possible. To secure this result various devices have been resorted to, a usual one being an eccentric, or some similar apparatus, by which the nut is thrown out of gear when the door is to be shut. Then the shutter falls down quickly by its own weight

(Fig. 6, Plate XXIX.). (This implies, of course, that the door is closing when the shutter is lowered, as is generally the case.)

The disengaging gear, as above described, is open to two objections :—(1) When released it leaves the door free to fall suddenly, and gives no means of checking or regulating the descent ; therefore it is dangerous, as the door may be released just at the moment a person is passing through. (2) When the shutter is down it is sometimes not easy to put the nut in gear again to force the shutter well against the seat frame. To avoid these defects, in lieu of the nut a brake is fitted to the door, as in Fig. 6, or two worm wheels with locking brake are fitted, embracing the screw shaft (Fig. 7, Plate XXX.). These wheels are locked fast when the shutter is raised, but can be made loose to any convenient degree when the shutter is lowered. When locked they act like a screw nut, in which a screw shaft is revolving. When loose, they simply turn freely and glide along the screw shaft. Therefore, the shutter can be regulated at will on its descent, and can be forced tight against the seat, when down, by simply tightening the locking brake, when the screw shaft can be used to force the shutter.

The tightening brake can be locked both from below and from above deck as convenient. The gear, whether rack and pinion or screw shaft and screw nut, is usually worked by hand; but now that electric power is generally available on board ships, the said manœuvre can easily be made by a small electric motor fitted to the hand shaft of each door, as shown in dotted lines on Fig. 8, Plate XXX. This arrangement, which has already been fitted on board ships of the U.S. Navy, has two advantages.

(1) The door can be opened and shut instantly by the person who wants to pass through, simply by making and reversing an electric contact.

(2) The closing of all doors that might happen to be open in time of emergency can be effected by a single person—by the officer in command on the bridge. The electric arrangement does not impair the efficiency of the hand gear (which is needed all the same, should the electric current fail), as, when the electric current is interrupted, the electric motor offers but little friction, and this can easily be overcome by the hand gear itself.

Possibly the same advantages might be secured in a more reliable and efficient way by using hydraulic instead of electric power. A simple, small, hydraulic cylinder, with reversing valve, fitted to each sliding door, and connected to a pipe carrying the compressed water, would be all that is necessary. The force for working a water-tight door being comparatively small, a small quantity of water at a very moderate pressure, such as is available on the feed pipes of the boilers of the ship, would be sufficient for the purpose. And, as in a sea-way the feed pumps are always at work, the feed water pressure for working the water-tight door would be always available and ready.

With the addition of a hand force pump and accumulator to supply the water pressure when the boilers are not at work, the whole arrangement would serve the purpose in a complete way, whether the ship is at sea or in harbour, and, being practical and reliable and of easy maintenance, the hand gear, which then would be superfluous, could be dispensed with.

The accumulator need not be large. With a water pressure of 150 lbs., a water capacity of a few cubic feet would be sufficient to work a dozen water-tight doors at a time, which number is ample even for a big ship.

The advantages above enumerated are, in my opinion, worth consideration. In fact, why are water-tight doors objectionable? Principally because they are kept open. And why are they kept open? Simply because the operation of opening and closing them is tedious and slow and fatiguing. Reverse this condition, give the man who wants to pass quickly through a door the means of opening it rapidly by simply pulling a small lever, let the lever, as soon as it is released, go back automatically and close the door after the man has passed, and then, I think, you will see the sliding water-tight doors fulfilling their important function of allowing a free communication between the main compartments of a ship, without impairing the safety of the ship. This refers to passage water-tight doors. For bunker doors which are necessarily kept open at sea, the difficulty would also be overcome by the hydraulic arrangement, as by handling a simple main valve the officer in command would be able to close, in a few seconds, all water-tight doors that might be open at the time.

A difficulty would still exist, to a certain extent, on board warships, where the bunker holes on protective decks are kept shut. In these ships the coal trimmers, on closing the doors, would be practically shut in the bunkers with no possibility of escape; a condition not very pleasant. And it is this fear of being so imprisoned that has prevented the success of all schemes for suddenly closing the bunker doors, as the coal trimmers, to avoid such an awful fate, contrive means for jamming the doors to prevent them being shut. Therefore, should any arrangement for closing suddenly the bunker doors be resorted to, it ought to be completed by giving proper means of escape to the coal trimmers.

The sliding shutters of water-tight doors, whether for bunkers, or for passage through compartments, when shut, are usually forced and kept tight against the seat of the door by means of inclined guides or wedges. This arrangement is open to objections, as the wedges are needless when the pressure of the water tends to keep the shutter automatically tight against the seat, and they are generally inefficient when the water pressure, acting on the opposite side, tends to force out and detach the shutter

from the seat. Moreover, the guide wedges, to be efficient, must press hard, with the result that the door is then hard to open.

To avoid these defects double-seat water-tight doors may be resorted to, which are automatically tight, whichever of the two sides of the door is pressed by the water. Figs. 7 and 8 show two double-seat water-tight doors, one vertical and one sliding horizontal, as fitted on board the Royal Italian cruiser *Elba*. Figs. 10, 11, and 12, Plate XXXI., show the same principle carried out for bunker water-tight doors, of which more will be said hereafter.

Double-seat doors are naturally heavier than single ones, but at the same time, they are more robust and rigid, which is advantageous in order to prevent deformation and insure tightness.

There being no wedges to tighten the shutter, as this function is fulfilled by the water pressure itself, the shutter, when the door is shut, in ordinary condition, is free to glide along the guides, with the result that little force is necessary to move it and open the door.

On account of this freedom double-seated doors can be also easily balanced with counterweights, in such a way that they will close gently by themselves as soon as the person who has opened them has passed through.

Double-seat doors have necessarily a grooved guide on the bottom or sill, which would be liable to get choked with dirt, unless it is kept covered, or, in some other way protected when the door is open. Fig. 7 shows an automatic cover as fitted to the vertical sliding door. In the horizontal sliding door (Fig. 8), the protection of the bottom groove is given by a tail-filling piece carried by the shutter to fill the bottom groove when the door is open.

Bunker Water tight Doors.

Bunker water-tight doors are generally vertical sliding, single seated, screw-shaft geared, and close, as usual, downwards (Fig. 9, Plate XXX).

These doors are generally acknowledged to be defective, on account of the coal that lies on their sill when open and which opposes an obstacle when the shutter is lowered to shut. Moreover, the pressure of the water inside the flooded bunker tends to open the door, which therefore is scarcely water-tight, specially at the bottom, where there are no wedges or guides to keep the shutter well pressed against it.

Both objections would, in my opinion, disappear if the door were made double-seated and to close upwards, as then it will always be automatically tight, whichever side of

the bulkhead is flooded; and the coal that might lie on the sill would fall down by itself, into the stokehold or the bunker, when the shutter was being raised.

Figs. 10, 11, and 12 show the working model of such a door. As will be seen, the door is double-seated and closes upwards, the shutter, when the door is opened, being lodged in a box at the bottom, and filling with its upper edge the groove in the sill. Nay, this upper edge forms the bottom of a frame cast solid with the shutter, and which fills the grooves of the door all round, and keeps them clear.

Moreover, top and bottom of the door aperture are not straight, but convex, and the corresponding edges, both of frame and shutter, are made sharp, to facilitate the crushing and shearing of the coal, should any piece of it rest on the top edge of the rising shutter.

The door is worked by the usual screw-shaft gear, gearing in a nut fixed on top of shutter frame. Of course any other gear might be fitted instead.

With the proposed arrangement the sill of the bunker door is higher than the bottom of the bunker by the whole height of the shutter; but, by limiting the height of the door opening to two feet, which is sufficient, the said sill, in ordinary cases, need not be more than a few inches above the boiler platform, as is usual at present.

DISCUSSION ON THE TWO PRECEDING PAPERS.

Rear-Admiral A. K. Wilson, C.B., V.C., R.N. (Associate): My Lord and Gentlemen, I think the meeting should be very much indebted to Lord Charles Beresford and to Colonel Soliani for bringing a subject of this sort before us. There are few occasions on which naval officers and naval architects can fairly meet, face to face, and discuss questions of this nature. We meet on service, in the dockyards, and so on, but we never get fairly face to face, as we do in a society of this sort. I think all naval officers will admit that the question of how our ships are to be made safe from the attacks of torpedoes, and from collisions—which I imagine is the main subject of Lord Charles Beresford's lecture—is a most interesting one to us. Having been captain of the sister ship of the *Victoria* at the time that vessel was lost, naturally my attention was turned very closely to the question of water-tight doors, and to the general subject of the cause of her going down. The whole matter is perfectly familiar to this meeting in consequence of the very clear minute made on the subject by Sir William White, but there are some points with regard to the doors which I think ought clearly to be put before us, and I wish first to impress on the meeting the importance of having a ship safe from, certainly, one torpedo or one collision. If we go to war, one of the principal uses of our ships will be to attempt—if we are strong enough—to blockade our enemy's ports. The main danger in keeping close in off an enemy's ports will be the torpedo boats, and if, when a ship is struck by one torpedo, the damage is only such that we can run across to the nearest dock, and dock the ship, and be out

in two or three days, the admiral would not hesitate to keep his ships in close; but, if the effect of the blow of a single torpedo was the sinking of the ship, he would hesitate about going near the enemy's ports. We all should like ships to be without water-tight doors at all—both naval officers and constructors—but we must communicate between the different parts of a ship, and I am not one to reduce the *necessary* communication in any way. The engineer wants to communicate between his engines and boilers, and I would give him free communication; but, as ships are now, you leave the engine-room platform, in most ships, and go down two or three steps, then through a door, and along from boiler-room to boiler-room; if, instead of that, you went up two or three steps, you would get your communication from boiler-room to boiler-room along a high level, and there would be a fair opportunity of closing those doors after a collision occurred. Doors in the bottom of a ship cannot be closed when a collision occurs near them. It is like trying to close the door at the bottom of a dock when you open the sluice gates—a man would be washed off his legs. You must assume that when a collision occurs, or when you are struck by a torpedo, it will always happen when you are not expecting it. When a man is run over by an omnibus it is when he is not expecting it, and therefore he cannot prepare beforehand; and it is the same thing with a collision. You must reckon to have a collision in peace, or be hit by a torpedo in war, at any time when you least expect it. The engineer, as I say, wants to communicate with all parts of his department, also the communication must be direct between the captain and practically all parts, that is to say, from the conning tower down to wherever he wants to send a message. The communication must also be direct between the 6 in. guns and the 6 in. magazine, and the big guns and the big guns' magazine, and the torpedo director and the torpedo tubes; but you need not go from one of these compartments to the other. The engineer does not want to go direct from the engine-room to the magazine, or the gunner from the magazine direct to the submerged torpedo room, or from the torpedo room to the capstan engine room, all of which places were in communication with each other in the *Sans Pareil*. They belong to different departments, and if each goes down his own hatchway you would not require a tenth part the number of doors we had in the *Sans Pareil*. I am obliged to deal with rather ancient ships, because I am not familiar with the *Magnificent* and other new ships. I know the arrangements are much better in the new ships than they were. The reason why, in the *Sans Pareil*, we had to go through so many doors was because of the armoured deck. If you make a deck with no hatchways in it you must have doors, and burrow under it by going from compartment to compartment. That was the main cause of danger and the cause of the *Victoria* being lost. If you divide, as I say, the ship into different compartments in this way, and have your engine and boiler rooms as one compartment without doors leading out of it, and your main magazine as another, without doors, your 6 in. magazine another without doors, and your submerged torpedo room another without doors, you have done a great deal to make your ship safe. The next thing I want to bring forward is that, when you are arranging these compartments you have to consider what is the effect of their being broached, on the ship. The compartment, when it is flooded, must be considered in three ways—as immersing the ship, as altering her trim, and making her heel; and you must consider all these things when estimating the effect of any blow from a torpedo or from collision. When I was in the *Sans Pareil* I calculated that if I had a compartment running right across the ship which contained 1,000 tons of water, it would immerse the ship in round numbers 2 ft. If I divide that compartment into two, by a bulkhead in the middle, so as to have 500 tons on each side of the ship, the result would be to immerse her only 1 ft., but to heel her at the same time, so that the ship's side would go down 6½ ft. Now, when you are in action, and before you are hit by either a torpedo or a ram, you will have been under fire some time, and there will be

a certain number of holes in your unarmoured side. I think that this is a certainty. The more you immerse the ship's side the more holes will go under water, and every hole through the unarmoured portion, which is not plugged, removes a certain portion of the stability of the ship. If I have my boiler room extending only half across the ship, and 500 tons of water got in, 6½ ft. of the side exposed to the enemy are immersed, and all the holes in that 6½ ft. are immersed instead of only in 2 ft. The next thing I looked into was the question of the other longitudinal bulkheads, that is to say, we have coal bunkers along the side. If we take a bunker in this same compartment that I talk of, that took 1,000 tons, and the bunker holds one-tenth of that, that is to say 100 tons, and if you fill the bunker on the side of the ship, it will immerse the side about 2 ft., that is to say, the side will be immersed about the same as if the whole compartment was full; but supposing you join your starboard and port bunkers by a passage, or big pipe, you will then find that instead of going down 2 ft. the side only goes down 5 in., and there is not only the question of the side going down, but, when you heel the ship, there is an immense difference in the comfort and ease with which the work is carried on. Sir William White, in his minute on the loss of the *Victoria*, pointed out that, where the collision occurred there were no main longitudinal bulkheads, but there were a few fore and aft bulkheads, that were made for the purpose of convenience—of localising stores and so on. Although they were so small, we find that when the ship's stability was reduced by the ship's side above the main deck being penetrated, and by the immersion of the ship's bow, these compartments, small as they were, were enough to capsize the ship. I do not pretend to calculate accurately these things, but I am under the impression, from rough calculations that I have made (you will remember, in the *Victoria*, one of the principal compartments on one side that was filled was the foremost coal-bunker, before the stokehold on the starboard side—a wing coal bunker), that if the starboard and port coal bunkers had been in communication by means of a big pipe (these are against my case, being well forward) the effect would have been to tip the ship a little more by the bow, but to right her to a considerable extent more. My impression is that the foremost battery port would have been raised about 2 ft. and the foremost battery door—which was the principal cause of the ship's capsizing, would have been raised 1 ft. This would have prolonged her existence, whether long enough to shut the ports, or doors, I do not know, but it would have been so much in her favour. You may say that this question of heeling the ship with side compartments is not directly concerned with water-tight doors; but it is, in this way—and this is a point that I want to impress upon the meeting—that if you will make your compartments so that the effect on the ship is not greatly to list her, you may have very much larger compartments, with the same degree of safety, and could therefore reduce the number of doors to a large extent; or, with the same sized compartments, you could have much greater safety. In boiler rooms—for instance, in the *Sans Pareil*—taking the ship in action, as I have said, with the holes in her side, she was actually safer with all four boiler rooms full than with one. It seems to me that the question of the system you adopt cannot be separated from the question of how many doors you are to have. The two things are so completely together, that it seems to me impossible to separate the one from the other. I have said enough to show the general lines on which I think the modification should be made to reduce the number of water-tight doors in a ship. Much of the difference of opinion in this matter comes from our not clearly understanding the conditions. When we come to consider, between the naval officer and the constructor, whether a door should be made here, or made there, the naval officer is not in a position to know exactly what the effect of the door will be on the trim of a ship when she gets into action, or collision, or when other things happen. An admirable suggestion was made to me by Admiral Makaroff, of the Russian Navy, which, I think, would put the naval architect and the naval officer

into the closest communication. He said that, when a ship was built or designed, an accurate model of her should be made in tin, or copper, the compartments being all represented by little boxes, which could have holes made in them to represent any given conditions. When the boxes were all in place the model should be adjusted with movable weights, so that its displacement and trim would be correct, and its metacentric height proportionate to that of the real ship, which would ensure the centre of gravity being in the right place. It would then be used, in the first place, in investigating any questions that arose while considering the design, or during construction of the ship, and afterwards be put on board the ship for the captain and officers to familiarise themselves with every question that cropped up as to how the ship would heel or behave under all conditions of damage. Such a model would be most useful, and I am sure would lead us to understand this question of doors much better than words. When we recommend a door here, or a door there, we should understand what the effect of its being left open might have on the trim of the ship. I am trying, my Lord, to keep as close to the subject as I can. I hope I have not offended the meeting in any way by straining the subject, but I think it is one that naval officers, and naval architects as well, are greatly interested in, and it is necessary to make the discussion thorough.

Sir William White, K.C.B., LL.D., F.R.S. (Vice-President): My Lord, Ladies and Gentlemen, I have come here to-day, without medical leave, to take part in this discussion, both because the subject is of great importance, and because it has been introduced in so comprehensive a way in these two papers. I propose to confine my remarks to the real subject of these two papers, namely, water-tight doors. Further, I shall have to limit myself even within those limits, for reasons that will be perfectly obvious to the meeting. It will be understood that I am not the person, nor do I think this is the place, in which I should say a word about the work done by our eminent professional French colleagues, or about French ships in general. I have had the opportunity, by the courtesy of the French authorities, of visiting French ships. I have been given the opportunity of going through those ships and seeing anything I chose. Therefore Lord Charles Beresford will understand me to be acting, not with any disrespect to him, but from what I consider to be a proper course of conduct, in not saying anything whatever in relation to French practice. Then, again, I do not propose to follow Lord Charles in his references to the details of particular ships, for the designs of which I am responsible. Whether or not there are 208 doors in the *Magnificent* I could not say off-hand; nor could I give the actual numbers of doors in any of my ships; because, for reasons beyond my control, I have not been able to look at the plans of one of those ships for many months past. What I have to say will, I think, cover all the principles which Lord Charles has attempted to lay down, and I presume that, after all, is the really important matter. I do not propose either to follow Admiral Wilson in his remarks on the question of the proper arrangement of bulkheads, or to discuss the relative merits of longitudinal transverse divisions. I perfectly agree with the principle he lays down; viz., that, in arranging the subdivision of ships, it is absolutely necessary—and it is our constant practice to comply with that necessity—to inquire what would be the effect of throwing open to the sea any compartment or compartments—the effect not merely upon the immersion, but upon the heeling and the change of trim. The practice of every competent naval architect in proposing arrangements for the water-tight subdivision of ships would embrace all these considerations, and the related investigations. Coming to the paper of Lord Charles Beresford—if I may take that first—I would thank him on behalf of the Institution, as a naval member, for taking the trouble to give us in this paper his own personal opinions. There is nothing lost by an expression of opinion, and we all know that, having given great attention to this

subject, he has formed very strong opinions. Moreover, in the paper he has expressed those opinions in very strong language, to which we take no exception. Still, there is an air of calm about Colonel Soliani's paper which is most refreshing as compared with the other, and I feel that we approach this discussion in all the better spirit because we have the two papers to discuss. The one may be called a technical review of the subject; the other a naval officer's view of what he considers to be most important features in the construction of warships. Lord Charles Beresford proposes three or four important things. The first—and I take it to be the most important proposal he makes—is a considerable diminution in the number of water-tight doors. I have already said that I cannot charge my memory as to whether there are 208 doors in the *Magnificent*, or not—I do not know. But when I come to examine how Lord Charles applies his principle to that particular vessel, I find (see p. 163) —and if I am wrong he, of course, will correct me—that of the 208 doors which, he says, exist in the *Magnificent*, he proposes to do away with only nineteen. Is that right?

Lord Charles Beresford: Read the context; it is below the water line.

Sir William White: Nineteen doors to be done away with out of 208: about 9 per cent.; that does not seem to me such a very sweeping change, after all. Going one step further, we are told in the paper that the feeling of the Naval Service is with Lord Charles. I listened with great pleasure to Admiral Wilson's speech, because he is a representative naval officer; and I hope more naval officers will join in this discussion, and give their opinions on this matter. It is important, however, that this meeting should be told what is the opinion of officers actually serving in some of our most recent ships. For the *Royal Sovereign* class we obtained, not very long ago, from the officers who had lived in and worked those ships, their distinct and clear report as to the doors that they would advise to be dispensed with. Whatever the number of doors was in the *Royal Sovereign*—it may have been 200, I do not know—the first suggestion was that one or two doors could be dispensed with; orders were given immediately that these doors should be closed and locked. So far as this inquiry went, therefore, there was a practical endorsement by competent and experienced officers of the actual arrangements of doors in that important class of ships. If I may hazard the remark in the presence of so many distinguished naval officers, I would say that any captain of a ship has the power of closing and locking any door he likes in his ship. If there is no access to a compartment, except through a door, of course he cannot close and lock it without preventing access. Such cases are, however, readily dealt with in practice, and this leads me to say that, I entirely challenge and traverse the statements made by Lord Charles Beresford to the effect that doors are necessarily and actually causes of weakness in bulkheads. If an opening is cut in a bulkhead it is no doubt somewhat weakened by the operation. But there are such things as "compensations" and strengthenings to make good the loss. If we were to act on the principle laid down by Lord Charles Beresford, that the mere weakening of a structure, by cutting an opening in it, was a fatal objection, we should not build ships at all. Let me be clearly understood. I do not say that openings are not sometimes cut in a form that causes weakness. But I do say that it is not necessarily so. If the door and its framing are properly fitted, and if the bulkhead is properly constructed near to the doorway, then I say that such a door, when closed and properly secured, is as valuable as any other part of the bulkhead; and it lies within the discretion of the commanding officer of any of Her Majesty's ships to carry out that arrangement which he considers to be the best in regard to closing doors or keeping them closed. Passing on to the question of what determines the actual number of doors in Her Majesty's ships; it has been frankly acknowledged by Lord Charles Beresford that this is not a matter in which the naval constructor is to be blamed solely, or even chiefly. The naval architect has to comply with the requirements of naval officers

to a very great extent. Therefore, in what I am saying, it will be understood that I am not speaking as an offended naval constructor—not at all—I am trying to state the case fairly. What determines the number of doors, and what considerations have to do with their positions? Now, history repeats itself. One feels much older when one remembers that we are to-day discussing practically the same subjects as were dealt with twenty years ago, after the loss of the *Vanguard*. I was then twenty years younger, and I looked on these matters in a less serious way than I do now. I well remember the papers which Sir Nathaniel Barnaby wrote after that accident, and the action he took, practically in the direction which Lord Charles Beresford is now recommending. Doors were to be diminished in number and placed higher in the bulkheads. Everything, in fact, was to be done to make the ship safer in the very directions which Lord Charles is now advocating so strongly; I honestly believe that the recommendations made in this paper are, for the most part, to be found in papers twenty years old. The identical principles now laid down were then recommended and given effect to in the construction of many ships. Now, what happened? We built ships in which the communicating doors in the machinery compartments were placed high up, with ladders leading to them. We built ships with exactly the arrangements which Admiral Wilson recommends, namely, with the longitudinal communications on one level, and at a considerable height above the floors of engine-rooms and stokeholds. These ships went to sea. Experience in those ships led to a reiterated and persistent demand from the commanding officers and engineer officers for communication at a lower level, and after long resistance it had to be conceded. These are matters of fact, not of opinion. That demand was made by the Service afloat, and there are many ships in the Service now which, in the earlier years of their career, had doors placed exactly in the position Lord Charles Beresford and Admiral Wilson recommend, but in which, after experience, in order to facilitate the working of the ships, the doors were placed at the lower level throughout the machinery compartments. While we all agree with Admiral Wilson in thinking that the ideal ship is that in which there are no openings in the bulkheads; yet it is also true that in every ship—whether merchant ship or warship—that ideal cannot be absolutely fulfilled. If a ship is to be capable of steaming over a long distance; if coal is to be transported readily in the large quantities necessary for high speeds, from the bunkers to the boilers; if the ammunition is to be carried through the ship, under protection, and delivered to the gunners, then there must be doors. Doors are inevitable, and the question of how many doors there shall be is one of the most anxious questions that either the naval constructor, or the naval officer working with him in the design of warships, can have to face. But it is absolutely the fact that the arrangements which are in existence in our ships are, to a very great extent (I might say almost entirely), the result of experience gained afloat, and at the request, the urgent request, of the officers who have served in those ships.

Lord Charles Beresford: Hear, hear.

Sir William White: Now Lord Charles says "Hear, hear." He is the first to admit that the opinion of his fellow officers, who have served in the ships, demands consideration and respect, and those alterations, which were made in the ships of which I have spoken, were not made rapidly or readily, but there was considerable and long-continued resistance to the change. But still the demand continued, and ultimately it was thought right and proper to comply with that demand in order to secure the power of long distance steaming at high speeds, and the power of working the ammunition, and adding to the capability of the ships as fighting machines. Besides that, there are questions of habitability which cannot be ignored, and there are questions of ventilation. It is perfectly true there is no mechanical impossibility in relation to ventilation; but, is it desirable

always to add to complication and to mechanical appliances, when, without danger, you can add so greatly to the comfort and habitability of the ship in the matter of ventilation? A ship is not always at sea, and she is not always exposed to the risks of which we hear so much in this paper. The question comes to this: Are we to consider the absolutely governing conditions to be those to which Lord Charles Beresford attaches the greatest importance, as securing most fully the buoyancy of ships; or, are we to so construct our ships that they are capable of performing their intended service efficiently as fighting machines, with certain communications through the bulkheads, the doors to which are fitted in an efficient manner, and most of which can be closed when at tactics, or in action, or under special circumstances? You must choose between the two policies. Lord Charles looks hard at one thing—it is a very important thing, no doubt—but it is, after all, only one thing out of many in the construction of a warship. If he ever has the opportunity, as I trust he may, of serving in some of these large battle-ships, I think he will somewhat modify his opinion as to the possibility of largely reducing the number of doors under all conditions of service. Turning to the question of the "'tween-deck" doors, I read this on p. 164: "In the case of the doors I propose to modify, the large doors should be replaced by small rectangular openings, close up to the deck, at the top of the bulkhead, as shown in sketch. This proposal is intended to allow officers and men to get from one compartment to another, quickly if necessary." It is my constant practice in going over ships to go into all parts, and even into the double bottoms occasionally; so that I know what it is to get through openings. I should like to see, as an "obstacle race," the quick passage of a body of men, first up a ladder, through a 2 ft. opening, and then down another ladder—especially under circumstances of emergency.

Lord Charles Beresford: I did not say that.

Sir William White: What size do you propose to make these doors; what is to be the opening? Your diagram indicates a small one. Will you tell us what the opening is? I do not want to say more than is in the paper, but I am correct in saying that about 2 ft. by 2 ft. was the size proposed. Lord Charles refers also to what the French have done with corresponding doors. This is his description of the state of things in the ships he visited:—"These openings are oval, and on the top of a coaming about 4½ ft. high. It is necessary to put one foot through, and then your bent head, to get from one compartment to another." This is hardly likely to facilitate rapid passage from one side of the bulkhead to another in circumstances of emergency or panic. Of course it does not matter much, because these openings in the 'tween decks, for the most part, need not be open under circumstances of danger. Further doors in the "'tween-decks" are usually so high up in the ships that there is no very great head of water or pressure to be dealt with, consequently hinged doors are usually fitted. For the same reason the question of the size of the openings, or that of a few inches, more or less, in the height of the sill, is not of great importance for doors in the 'tween decks. When the pressure of water is small, and there is no great rush of water, a man is not afraid to stand on deck and work these doors. In short, the circumstances are entirely different from those prevailing in doors fitted low down in the holds. There, all principal doors should be sliding, not hinged, and worked from above as well as below. With respect to the statements made by Lord Charles Beresford, to the effect that even with the trained and disciplined crews of H.M.'s ships, water-tight doors are frequently not properly closed when orders have been given to close them, I should like to hear the opinions of other naval officers present. Do they agree with the statements made in the paper about the loose and casual way in which water-tight doors at drill are closed? It does not seem to me to be quite a desirable thing that such statements as those should be made publicly without conclusive evidence. So far as my limited

experience afloat goes, I have seen nothing of the kind, nor have naval officers given me such an impression. But if Lord Charles is correct, then obviously there is a change wanted. With the "human factor" the naval constructor has no concern. If the appliances are correct, if they are efficient in condition, then of course the question of their use is one for those in charge. I will not say more, but that is a fact, and a fact we should not forget. There is a suggestion in the paper that the collision bulkhead should be placed further aft. As a matter of fact, all our ships have practically two collision bulkheads.

Lord Charles Beresford: With doors in them.

Sir William White: I will say a word about that afterwards; one thing at a time. They have two collision bulkheads, which we think preferable to one; we may be prejudiced, but we do think so. Another interesting fact is this, and it is always good to go to facts. Even in the disastrous collision between the *Camperdown* and the *Victoria*, where the powerful bow of the *Camperdown* bored so deeply into the side of the *Victoria*, the dreadful accident to the collision bulkhead, which we are told by Lord Charles must happen, did not happen. The collision bulkhead of the *Camperdown* was perfectly efficient after the collision. We have so many risks to face, so many things that are real to undertake, that we have no need to exercise our imagination unduly as to what may happen, when we can turn to facts having a direct bearing on the supposed danger. If the collision bulkhead fails in one of our ships there is the second bulkhead, and, in the case of the *Kœnig Wilhelm*, Sir Edward Reed will bear me out in saying that it was the second bulkhead that saved the ship. The armoured bow was twisted in such a way that it destroyed the integrity of the collision bulkhead, but the second bulkhead held good. Another point must be mentioned. This has a bearing on Lord Charles in his capacity of a judge of structural strength and his criticism of the middle line bulkheads as fitted to Her Majesty's ships. We are told that these middle line bulkheads are inefficient. Fortunately, or unfortunately, I do not know which, we can refer to events which show that the bulkheads are efficient. When the *Howe* went ashore at Ferrol the middle line bulkhead in the boiler rooms was subjected to enormous pressure for hours. The boilers on the side of the ship most distant from the reef gave steam for hours, although on the other side the bilge of the ship had been ripped open and the boiler rooms had been flooded. As the ship settled down and the bottom of the middle-line bulkhead ceased to be intact, the water passed from the flooded boiler room to that on the other side, but the middle-line bulkhead did not fail. These are interesting facts, and I could quote others. To the best of our judgment and ability, if we put a bulkhead into a ship we try to make it strong and able to do its work. It is only human to err, but I do not think in this case there is any proof that we have done so. Now, having said so much adverse to this paper, let me repeat what I commenced by saying, that I am sure all the professional technical members of this Institution welcome most heartily Lord Charles Beresford's attacks on the naval architects' part of this work. We think we can reply to the attacks, and we are glad to have his views upon all these and other matters. About the second paper I should like to be allowed to say a few words. Colonel Soliani did not wish to contribute this paper, but, at my urgent request, he did so, and I think the members of the Institution will be very glad that I was able to persuade him to come here and read it. A more thoughtful summary of the facts, in relation to water-tight doors and their working, their present arrangements, and their possible improvements, I think it is impossible to find anywhere. The Institution is under very great obligations to him. Besides writing this paper and putting before us his views on the general question, he has described the double-seated doors which he himself designed, although he was too modest to say so, or to inform us that they have been fitted in the *Elba* recently building at

Castellamare. Finally, he has taken the trouble to come all the way from Italy to read his own paper. There is one point I should like to refer to which is very wide in its bearing: that is, the question of the application of power to the working of water-tight doors. The ultimate form of such schemes is to give the captain in the conning tower the power of pressing a button and closing any or all of the water-tight doors. That is mechanically possible, and, if one may again refer to ancient history, in the *Polyphemus*, built a good many years ago, that principle was actually applied to the letting go of the detachable ballast. I do not know that the ballast was ever let go except in dock, but it could be done. It is not a question of mechanical difficulty, but desirability. So far, in ships of the Navy, we have not thought it desirable, or well, to add to the existing mechanical arrangements such arrangements as those, but rather to depend on dealing with each door at the door, and having the assurance of some responsible person that the doors have been closed when the orders have been given. I have to thank you, gentlemen, for listening to me, and to apologise for the length of these remarks.

Rear-Admiral C. C. P. FitzGerald (Associate): My Lord and Gentlemen, it seems to me that the Institution of Naval Architects has latterly taken to opening its proceedings with what we might call a naval skirmish, by way, no doubt, of clearing the air for those more abstruse subjects which are to follow. I think the paper which Lord Charles Beresford has read is eminently calculated to get up a naval skirmish. I have the misfortune to disagree with the noble lord in the views he has put forth, and I feel a little diffidence in expressing my dissent, for I have had the misfortune to see to-day's *Punch* just before I came here, and I saw there a picture of the noble lord with a bowie knife in one hand and a five-chambered revolver in the other, standing over a decrepit and blindfolded admiral, who had ventured to disagree with him. I cannot believe that Sir William White has seen this picture, or he would scarcely have ventured to differ with Lord Charles as he has done. This controversy about doors is a very old one, as you all know, and I thought it had been thoroughly threshed out. What must have struck the meeting, I think, is the change of position between the constructors and the naval officers (assuming that Lord Charles represents the naval officers). It has always been the constructors who have put up impervious bulkheads, and the naval officer who has asked to have holes cut in them, finding he was unable to work his ship without holes. I was surprised when I found that this paper took an opposite view. I may mention one instance, amongst many, where doors have been found necessary. In the last ship I had the honour to command, the *Collingwood*, I found that all the bulkheads between the engine-room and the stokeholds, and between the various stokeholds, were intact, with no doors in them. In consequence, very serious injuries occurred to the boilers, which I need not specify, because I daresay engineers will quite understand what happens to a boiler when there is insufficient supervision by the chief engineer. I weighed the question well—I knew there was a certain amount of risk in having doors—and I took what I considered was the lesser of two evils, and I asked to have doors cut. This was agreed to by the Admiralty. I mention this, as it is an instance of the practical necessity of doors to enable us to work our ships. I remember in Brassey's "Naval Annual" of 1894 I saw a very good remark of Mr. Thursfield—that well-known and talented writer on naval subjects—in which he put the case in a nutshell, and it was so good that I thought I would copy it. He says: "'Your ship shall not sink if you do as I tell you,' says the constructor. 'But I cannot work and fight the ship if I do as you tell me,' replies the executive officer; and here the autonomy seems to be complete. The doors are obviously meant to be sometimes open, or they would not be there at all." The whole tendency of the controversy hitherto has been for us, the practical men who have to work

the ships, to get the doors cut, and for the constructors to be against them. Lord Charles Beresford has shown us in his paper a sketch of what he considers to be an ideal door: here is a ladder with five steps on it, a little square hole—which Sir William White rather severely criticised—and another ladder down the other side. No doubt if our chief engineers were fitted, like those mechanical monkeys that go up a stick, and turn head over heels and come down head first on the other side, that door would be a very useful one; but, unfortunately, those talented and very practical gentlemen who are in charge of the engines of our ironclads are generally not exactly in the first bloom of their youth, and some of them are of somewhat portly figure, so that they would not find it easy to perform that acrobatic feat, and the consequence would be that, the boilers would not receive that amount of supervision which is necessary for their safety and preservation. It is an excellent ideal door, but not a practical one. I rather think that Sir William White criticised that door with some severity—I did not quite catch what Sir William White said—but it is all very well for the noble lord to talk of the convenience of the different compartments, in a somewhat contemptuous manner. He says, there is no doubt about this, that the safety of the ship is infinitely more important than the convenience of the different departments. That is true, no doubt—indeed it is a truism, or self-evident fact—but we must remember that it is the accumulated convenience of the different departments which makes up the fighting efficiency of the ship. That is the real point, and in considering the safety of the ship you must consider her fighting efficiency, and I do not think I am wrong in saying, it is all those little conveniences for people getting about and passing up ammunition, and supervising boilers, which go to make up fighting efficiency; and this is what we are all aiming at. The noble lord says in his paper, "My object in writing this paper is to invite discussion from those shipbuilding experts who are best able, by argument, to prove that those who agree with me on this all-important question are right or wrong." No doubt they are, and I daresay some other shipbuilding experts will follow Sir William White, and dispose of some of the arguments which Lord Charles puts forth. Colonel Soliani's paper I will not attempt to deal with. It is of a very technical character, and, if we are to have doors, he points out very ingenious mechanical devices by which they can be made reasonably safe. But I venture to express the opinion that, so far as Lord Charles Beresford's paper is concerned, he has not adduced any evidence to show that, in our more recent ships, any useless or unnecessary doors have been cut. He has asserted it, but in the absence of any evidence I am unable to accept the assertion, and, on the contrary, I entirely dissent from his opinions.

Vice-Admiral the Hon. Sir E. R. Fremantle, K.C.B., C.M.G. (Associate): My Lord and Gentlemen, I do not intend to detain you at any length, and I wish to confine myself to the practical points which have come under my notice. This question, as Admiral FitzGerald has told us, is a very old one, and Sir William White told us the same thing. I was certainly struck, in Lord Charles Beresford's reference to the question of separate compartments unconnected by water-tight doors, that he referred to it from the point of view of the seamen, the constructors, the engineers, and so on; but he left out one of the most important officers in the ship, and the qualifications which deal most directly with the question of water-tight doors, which were touched upon to some extent by Sir William White—namely, the habitability of the ship; I think, accordingly, that the doctor ought to have been mentioned in connection with the other officers. I cannot admit that this is, to a great extent, a duel between the naval officer and the constructor. I agree with Admiral FitzGerald that the naval officer is quite as much interested, and more so, in the habitability of his ship, and the smartness of his ship, and that there should be the freest communication between the compartments of his ship, as he is that she should be seaworthy, and that she should be safe in case of action and in case of danger,

and I think it very much to the credit of Lord Charles Beresford that he has to a great extent risen superior to the ordinary prejudices—the day by day prejudices—of the naval officer on this question. Now I pass from that, and, as I said, I will restrict myself to one or two subjects of practical importance. I wish to refer to one remark made by Lord Charles Beresford which was referred to by Sir William White. He says: "As all captains well know, the men will run down, if allowed, heave one or two hanks over a vertical door, or let fall a horizontal door without screwing up all butterflies, and report it closed, which is true, but the door is not properly secured." Now Sir William White seemed to look upon that as rather a reflection on naval officers generally, and on ships' companies generally. Now when we are in competition we are apt very often to do things hurriedly, and to do them more smartly than efficiently. On that point I can give you a little practical information. It was an incident which occurred to myself when out in China in the *Centurion*. I said to my flag-captain, "This is all very well, this closing the water-tight doors, but I should like to know when they are closed in this smart way, in a minute and a half, which you tell me they close them in, whether they really are closed properly"; so, without saying anything to the executive officer, I sent for the fleet engineer and the first lieutenant, and on all the doors having been reported closed by the watch as they usually are—the captains of the tops running up in a hurry and saying, "That door is closed, sir," and so on—the officers I just referred to went down immediately to see whether they were well secured, and I am happy to say the report was an extremely satisfactory one. I confess I was a little surprised myself that it was so satisfactory. At the same time, it is all a question of trouble, this closing of water-tight doors, and I cannot but think there is a great deal of wisdom in the remarks made by Colonel Soliani, that they should be capable of being closed with facility, and if they were capable of being closed and opened with facility we should have less difficulty with reference to closing them, and they would be more frequently found closed when the critical moment arrived. Personally I am entirely in favour of the principle of what Lord Charles Beresford has brought before us. We were challenged by Sir William White—he said there was nothing to prevent any naval officer from closing any doors he chose. I am aware of that. We have plans for closing the doors, and orders for the closing of doors. I myself gave very stringent orders, shortly after the loss of the *Victoria*, as to which doors were to be closed; but, after a little time, no doubt, there was a very strong pressure put upon us to have a good many of them reopened on the ground of health, and that, most decidedly, was necessary. My flag-captain, Captain McQuhae, had taken it up very warmly, and he used to be constantly coming to me and saying, "I am afraid, sir, we must relax the order somewhat. The doctor is complaining that the men cannot keep their health down below unless these doors are open." And I had to relax the order for permanently closing certain water-tight doors very considerably. I should like the question to be gone closely into—as is the wish of the lecturer—to-day, and if he can abolish any water-tight doors it is best, on the whole, that bulkheads should be left intact, and that officers should not have the option of leaving the doors open. That, of course, can only be carried out to a limited extent. We must have the power to open a considerable number of doors, and keep up sufficient ventilation in the ship. There is only one more point that I think it interesting to refer to, that is with reference to the war in the far East—the China-Japan war. In the Yalu battle there were two ships sunk. I have reason to believe that the *Chih Yuen* was sunk mainly by gun-fire, though some people think she ran over one of her own torpedoes; but she sank in the upright position, and certainly was lying on the bottom in an upright position, because I saw her afterwards with her tops just above the water. Then there was the *King Yuen*. Unquestionably the *King Yuen* capsized, it is generally supposed through gun-fire. It was stated that she had been badly on fire, and that the captain had flooded one of the magazines, and so given the ship a list. At all events, I

think it was proved that she had a very large list when she was last seen, and was listing towards the Japanese, who fired through her deck, and she sank—capsizing as she sank. Then I can go to the vessels at Weihaiwei. The *Ching Yuen* was sunk by gun-fire. I believe she sank very rapidly, but in an upright position. Other vessels were destroyed by torpedoes, the most important of which was the *Lai Yuen*.* She was a vessel of 2,900 tons,† and she had an armoured belt, and a certain amount of protection. She was sunk by a torpedo, and I think it is clear she capsized in about five minutes. A good number of her crew were naturally lost, and I myself, a day or two afterwards, saw her lying bottom upwards in the harbour. I should like, on that point, to remark that it seems to me that ships have a strong tendency to capsize when wounded below water. I am speaking of men-of-war, and perhaps it is true also of merchant ships; and anything we can do to add to their stability (although I believe it is true that our ships are very stable, and more so than the ships of foreign Powers) is worth doing. I am afraid, gentlemen, that I have detained you too long, and I will not attempt to go into the technical questions as to the size of water-tight doors, or how they are best secured, but I merely say, in conclusion, that I entirely agree with Lord Charles Beresford that the fewer doors we can have the better, and the easier they can be opened and shut the better; and the more we can provide our ships against the possibility or the probability of capsizing, the more I think we shall be going in the right direction.

Vice-Admiral P. H. Colomb, R.N. (Associate): My Lord and Gentlemen, I think we are having one of the usual interesting discussions between the Navy and the constructors, but I should like to draw your attention to a very pregnant remark of Admiral Wilson's, that meetings of this kind are almost the only ones where the naval officer and the designer come into free and open discussion. I think that is the important point raised by the whole of the discussion that has gone on to-day. It is clear from what we have heard, that the naval officers who have spoken are in agreement with Lord Charles Beresford, that is to say, that a supreme effort should be made to get as few openings in bulkheads as possible, and that the naval officer distrusts the human element when it comes to a question of water-tight bulkheads. Now I think we must allow that the naval officer is the best judge on that particular point. We know quite well what our people can do, and what we can do ourselves, and when officer after officer gets up and says it is not safe to bring in the human element more than you can possibly avoid, it stands to reason, I think, that that statement is correct and true. We must all have noticed the extreme skill of Sir William White in his answer. To me it seemed a brilliant performance, and I am sure we are all of us very glad to know that Sir William White is able to come amongst us again with his full intelligence and full vigour, and to make the answer he did. I have had myself many slatings from Sir William White, and I hope to have many more yet to come, because he slates you in such a pleasant way that, you cannot help thinking—though you may disagree with him—that he is doing it with extreme skill, and flicking you just as a skilful

* This statement is liable to be misunderstood. The *Ting Yuen*, Admiral Ting's flagship, an ironclad of 7,400 tons, was sunk by torpedoes at Weihaiwei, but though badly damaged, she remained afloat some twenty-four hours after having been struck by a torpedo, and sank gradually in shallow water, so that she had no opportunity of capsizing.

† It is curious that the *King Yuen* and *Lai Yuen*, both of which capsized, were sister ships. The *Chih Yuen* and *Ching Yuen*, which sank in an upright position, were also sister ships. The two former ships were 2,900 tons, the two latter 2,300 tons. The two former had an armoured belt, the latter an armoured deck.

driver flicks the lazy one of his pair. If I were in Lord Charles Beresford's place I should certainly be saying to myself, "'An I had known he was so cunning of fence I had seen him damned ere I had fought with him.'" But to become serious for a moment. The point which is impressed on my mind is, that questions of this sort arise, because there is not free enough and close enough communication between the naval officer who has to work the ships and the designer who prepares them, and I am justified in saying that that is a point which has been before the Admiralty in former times in a distinct form. When Lord Northbrook was First Lord of the Admiralty he had more than one long conversation with me upon that particular point—as to how it might be possible to bring the naval officer closely into the initiation of the design; because—as he put it and as I agreed with him—it is very difficult indeed to make changes after the design has reached a certain stage. You noticed that Sir William White's reply to Lord Charles Beresford was practically that, if we have too many water-tight doors in a ship it is the naval officer who puts them there, and not the designer, and Admiral FitzGerald to some extent has confirmed that; but what does Admiral Wilson point out to us so clearly? That in these cases—such a case, for instance, as whether a door is necessary here or there—the naval officer, when he is asked to give his opinion, has not heard the other side fully. He does not quite know, and is not fully informed of, the designer's view of what the consequences of any advice he may give will be. He gives his advice as a jury might give their verdict if they had only heard the plaintiff's statement and evidence. Thus I come again to the point that the practical issue of such a discussion as this ought to be to bring the designer and the naval officer closer together at the very beginning of the design. I will just give you, to conclude, the simplest possible instance of what I mean. I was, for particular reasons, specially interested when the *Amazon* was run down and destroyed by collision in the Channel. The immediate result of that collision, as far as the designer was concerned, was the establishment of the collision bulkhead even in wooden ships. A year or so afterwards I commanded a sister ship (I did not newly commission her) with one of these collision bulkheads, and having been interested in the whole case before, I naturally took great note of what this collision bulkhead was, and what it might mean. I found it had a sluice valve connecting it with the rest of the ship, and it was so arranged that, if the sluice valve had been raised and from any cause could not be closed, the value of the collision bulkhead was destroyed. I found that my predecessor in command had been very particular in seeing that this sluice valve should be constantly worked, and it was kept thoroughly well oiled. I found that the only object in having the sluice valve at all was to enable the pumps to drain the water which might come into the compartment before the bulkhead. I reflected that if a collision occurred, the very last thing you would want would be open communication between the rest of the ship and the compartment before the bulkhead. I found that the inconvenience of drying up the small leakage in the compartment was trifling. I accordingly ordered the valve to be screwed down and secured so that it could not be opened, and I felt pretty certain then that the bulkhead would do its work if it happened to be called on. Now, how did it come that there was a sluice valve there at all? It could only be to suit the convenience of the naval officer; but if the naval officer had had the whole case before him, as I had, he would have pointed out that the convenience was in no way commensurate with the danger that was run by establishing the sluice valve. If you carry that illustration, which is on the simplest and smallest scale, and connect it with what Lord Charles Beresford and Admiral Wilson in succeeding him said, I think you will agree with me that the point to be got at is that before the ship is designed let the naval officer and the designer come into close connection, and continue so, and they will design a system of bulkheads which will require the minimum number of water-tight doors.

Mr. B. Martell (Vice-President): My Lord and Gentlemen, after all that has been said, and so exhaustively said, I should not have thought it necessary to make any remarks, were it not that there has been so forcibly brought to my mind an observation made by Admiral Colomb; and that is, the remark that he found in the vessel he commanded a sluice in the collision bulkhead, and this iron sluice he had closed. I may say with regard to mercantile ships which we have coming under our notice, that formerly we had sluices in the collision bulkhead, but we found that many inconveniences resulted from them—that a vessel, for instance, is more apt to get her bow injured than the other parts, and, when such accident occurs, the water finds its way into the fore peak; and often, owing to the sluice valve in the collision bulkhead not being down at the time, the water finds its way into the hold, and the cargo is damaged. The consequence was that we considered it desirable to make a rule, distinctly stating that there was to be no sluice whatever in this collision bulkhead. We found such inconvenience attending sluices in other parts that we did all we could to deter owners and builders from adopting sluice valves in bulkheads—indeed, we went so far that we said, "If you put a sluice valve in a bulkhead you must find some means of getting access to it." I am now talking about mercantile vessels. With regard to vessels loaded with grain in particular, those sluice valves used sometimes to get choked up with grain, and water was confined in the hold, and it was impossible to find its way into the engine-room, where it could be pumped out; and therefore we have done all we can to dispense with sluice valves altogether, with the exception of in the engine-room bulkhead, where there is pumping power, so that any water finding its way into the engine-room can be pumped out. Now, my Lord, this paper seems to resolve itself into this: the Admiralty are differently situated from what we are. We make rules for mercantile ships, and those owners adopting those rules for the classification of their vessels, frequently press us, with all the pressure they can bring to bear, for certain deviations from those rules. They say, "If you will not allow us to have doors in this bulkhead it is impossible for us to work this ship to advantage, in consequence of the special trade in which she will be engaged." Not to be obstructive, we do all we can to facilitate trade (which, I need not say, is of very great importance), and, having due regard to safety, we often say, "Provided this door be properly and efficiently fitted, to the satisfaction of our surveyors, we will allow it in this instance." But the Admiralty are differently situated in this way; they are the owners themselves. They can insist on what they will have, and they are not subject to any pressure from outside as regards their arrangements. I do say this question of doors to water-tight bulkheads is a matter of very serious consideration, and I sympathise with Lord Charles Beresford's remarks very much indeed. I believe in warships, where it is a question of the safety of the ship with regard to bulkheads that are intact—some of them have ten or twelve main bulkheads—if you could insist on those main bulkheads being intact the safety of your ship would be insured. There is no doubt about that. They divide warships in such a way that any two compartments can be filled and still the ship will float. It is not often that two compartments would be filled; if the main bulkheads were intact from the kelson to the deck the ship's safety would be insured. What a comfort it would be to those on board to feel that, in the event of a collision, or perforation from any cause whatever, a compartment being filled, the ship would neither capsize nor sink. That is a matter of the utmost importance with regard to warships, and too much importance cannot be attached to it. When I am squeezed and am obliged to do things, it makes me feel that I should be glad if I were in the position of the Admiralty officers, so that I could make a definite rule and say, in all these great subdivisions—where you have ten or twelve of them—it must be a binding rule that all those bulkheads must be intact, and must not be perforated. I was very much surprised to hear what Lord Charles Beresford said with regard to those French ships; it is, no doubt, going in the right direction, and shows that they realise the importance of this. I can

only hope that some means may be found whereby the pressure of officers and engineers could be dealt with by the Admiralty with sufficient moral courage to lead them to say: "No, sir, we will not have these main bulkheads perforated; the safety of the ship and the lives of the crew are of far more importance than your convenience, or the convenience of the engineers."

Rear-Admiral FitzGerald: No! no!

Mr. Martell: Admiral FitzGerald says no. Allow me to say that, although you are a great naval officer and have these men—hundreds of them—under your control, the safety of the ship and the lives of those men are of far more importance than the convenience of the engineers. I say that unhesitatingly, and I appeal to anyone here. There is no doubt that a large number of these doors could be dispensed with, with perfect safety, if it were not for interfering with the convenience of the engineers and of the officers in getting about, and every door that could be closed in that way would be a source of greater safety to the ship. Sir William White says you may have doors, and that it is left to the naval officer to shut them up if he likes. Would it not be far better not to have any door, and not to open up the temptation by having a door there? Of course doors there must be in connection with the magazines, and the firing of the guns and the quick service they want, but I would have a man stationed at every one of those doors—they need be very few in number—let there be a man at every one. You say to him: "That door is under your charge; you look out and see that you have it under control." With regard to what is below water, after what has been shown in Lord Charles's paper, and what has come under our notice—I do contend that the time has arrived when we should certainly try to make the main transverse bulkheads of ships intact, and obviate any opening whatever being made in them. With regard to the fore-and-aft bulkhead in the engine and boiler space, there is no doubt that there is no necessity for having these great openings. We know that, although engineers so boldly and courageously do their duty down in the engine-room in times of danger, which they have done in lots of instances, and have earned our commendation for the pluck and courage which they have exhibited, still if they were called upon, and it was said to them, "We cannot allow you to have communication in this way with doors without involving the safety of the ship to a much greater extent than we think is right," they would concur in doing away with a lot of the openings that are in them now, and which are, in my opinion, quite unnecessary. With regard to Lord Charles Beresford's idea of the weakness that these holes make, that is a matter of no importance. I agree with Sir William White that those bulkheads can be made sufficiently strong, and I do not believe there is any weakness occasioned by them. It is a mere local opening, and does not interfere with the strength. There is another great point which I think may be considered, and that is, these large steam-pipes going through these bulkheads. You cannot, when a ship strains, have these joints tight, and it is well known that, in some instances, water finds its way through these with very great ease; but that might be obviated to some extent by having your steam pipes carried up and round, instead of going through the bulkheads; or it might be done in some other efficacious manner. I contend they could be carried up sufficiently high not to interfere with the safety of the ship, and therefore I have a strong opinion that this is a question between the Admiralty, who have the control of this entirely in their own hands, as to what should be allowed, and the officers and engineers, and if it was any other question whatever, and such a point as that arose, I feel sure they would do all in their power to obviate unnecessary dangers.

Mr. A. E. Seaton (Member of Council): My Lord, and Gentlemen, it appeared earlier in the day that the contest on this important question was between the naval officer and the naval architect; it

turns out now that it is the unfortunate engineer who is at the bottom of it. As an engineer, I rise to speak on the subject, and I do so, inasmuch as I quite support Lord Charles Beresford in his contention; I have, however, done something more, for I have from time to time successfully carried out my ideas as to water-tight doors. I am astonished to find that the naval element to-day, in its attempt to deal with Lord Charles, has not gone back into more ancient history. We have been taken to the sixties—the *Amazon* having run down the *Ceres* in 1866, I think. But in 1782 there was a most disastrous accident due to the leaving open of doors which should have been closed, whereby Admiral Kempenfeldt lost his life: we have had no allusion to that to-day, but it is a fact that, with regard to the *Royal George*, the lee ports, which should have been closed, were left open for ventilation. The result was that Admiral Kempenfeldt, who, notwithstanding the heavy list on the ship, was writing in his cabin, lost his life with some 800 men. Now, it may be said that the moral of that is, do not have gun ports on your lower deck, which is a moral that might be turned against me if I said too much about it; I have alluded to it, however, as one of the instances in history in which through absolute neglect with doors a most valuable ship was lost with 800 lives. The naval officer, it appeared to me, was open to be either drowned or asphyxiated, but Mr. Martell has introduced a fresh subject for contention to-day in the question of the sluice valve. There is no pleasing naval officers, and sometimes not even Mr. Martell. Admiral Colomb, in quoting the case of the *Amazon*, spoke of her as if she should have had water-tight bulkheads. The *Amazon* was a wooden warship, and she ran into an iron ship; the damage she did to her bows was so great that she sank very soon after the *Ceres*—the iron merchant ship. I know that the result of that collision caused more attention to be paid to collision bulkheads; but collision bulkheads had been fitted to ships many years before the *Amazon* sank the *Ceres*. It was so in the case of the Mercantile Marine, and I have a little bit of evidence to give that it was so in Her Majesty's Navy. No doubt many naval officers will remember the *Black Prince* at Portland, in about the year 1868, ran into the *Royal Oak* and distorted her own cut-water very much indeed. When she was put right in Devonport Dockyard, in accordance with Government practice, the fore peak was filled with water and tested: that water was never let out until many years after. I suppose it was in consequence of the bulkhead not being fitted with sluice valves, or something of that kind—I do not know, but I presume that the dock people found that they had got the water in and could not get it out, and therefore they let it stay. But the fact remains that that ship carried the fore peak full of water for years. It was discovered by an admiral who was very much interested in water-tight compartments, and the means of access to them, and who, searching the ship and finding no entrance to this fore peak, determined to have one at any cost, and on making it found it full of water. I rose, however, to speak about the unfortunate engineer, who is supposed to be so malignant as to insist on having access to the engine-room and the boiler-room out of sheer "cussedness"—but it is apparently laziness. I have insisted, whenever I have had the power to do so, on the bulkhead between the engine-room and the boiler-room, and between the boiler-rooms, being unpierced with water-tight doors, or any other form of doors. In the ships of a particular fleet, where I was allowed to have my own way, there are two boiler-rooms and one engine-room. In that case I persuaded the owners to let me fit the bulkheads unpierced by doors of any kind, and, as they were anxious that it should be well known that their ships were made as safe as science and forethought could make them, they agreed with that; and I have heard no complaints. The only application we had from the engineers' department was that we should fit them with mechanical telegraphs between the engine-room and the stokehold, having simply the words on them, "stop," "easy," "half-speed," "full speed," "more steam." Those are very easy signals to be communicated, and are all that are necessary. If there is

an excuse for the engineers to have easy access, it is in those ships; because, instead of having—as they have in Her Majesty's Navy—a large staff of trained engineers, they have only two, one in each watch, and therefore the excuse would be to make things as easy as possible for them; but these ships are run, night after night and day after day, without any complaint from the engine-room staff, by the simple means which I have indicated. I do not see why, in Her Majesty's Navy, there is a need for this piercing of bulkheads, and I can see good reasons why it should not be done. In the first place, the vital part of the ship is subdivided in order to make it as safe as possible; then they have these doors put in, which anybody knows are thoroughly unreliable in the case of accident, in order that an engineer (I do not know whether the chief or some of the staff) may run in and out of the boiler-room occasionally without any trouble. In Her Majesty's Service, with the trained staff they have, I should have thought that if the engineer on watch had a sufficient supply of steam, that was all he wanted, and that the occasional visit to the stokehold might be made without great inconvenience by going above the deck, and along, down to the stokehold. These are days of science, and we fit merchant ships with telephones, why cannot we do that to Her Majesty's ships? I would not have a single water-tight door more than was absolutely necessary, and if the doctor was not happy without them, I would let him have some extra ventilation by some other means than opening the vital parts of the ship to the inrush of water.

Professor J. H. Biles (Member of Council): My Lord and Gentlemen, Mr. Martell has given us another instance of his many-sided ability. I am sure that we all regret that among his vocations he has not been able to take the position of Admiral of the Fleet. He would have been of great assistance to naval officers in arriving at the best arrangement of their ships, and what to do with regard to bulkheads. The early history of bulkheads is beyond my personal knowledge, but I have been assured by gentlemen who are in this room at the present moment—if they would only see fit to speak—that the earliest iron battleships that were built, were built without doors in the bulkheads, and that the doors were asked for in the first place by those naval officers who had charge of the ships, for convenience in working the ships. That is the beginning of this subject, and we do not seem to be much further ahead to-day than we were in the sixties, on this important question. The question, it seems to me, has been argued by Lord Charles Beresford and those naval officers who followed him, very much upon the lines of existing ships, but I take it that the question is a wider one than that—whether it is not possible to make a ship which shall be capable of being worked to the satisfaction of those who now object to the inconveniences that exist in ships that have not bulkheads pierced by doors. That question, I think, is capable of solution in some cases, and not in others, in the direction in which naval officers wish it to be solved. In broad ships there is great opportunity for carrying out what is really the principle to be aimed at, and that is, to have all that is necessary between two transverse bulkheads completely under control, and self-contained in that one space. Perhaps I can illustrate it better in this way. Take the case of some of our largest battleships, which have two engine-rooms and four boiler-rooms; that is, six compartments. Now, the line of communication that is necessary for the engineers is in a fore and aft direction. That line of communication is objectionable, because it causes holes to be cut in the bulkheads. Now, if we could have the ship so arranged that the line of communication should be transverse, I think there would not be anything like so much objection to it. It seems to me it would be possible in these large ships if, instead of having twin-screws and four boiler-rooms, we were to have three screws, three engine-rooms, and three boiler-rooms, each engine-room having its boiler abreast of it, and therefore being completely contained and completely under the control of the engineer,

who could get from his engine to his boiler without any interference in the shape of a bulkhead, and we might do away with the danger of having to pierce holes in the bulkheads. It is evident that that can only be done in special cases when the relation between the beam of the ship and the power of the ship admits of it. I think it might be possible to carry out some arrangement of that kind, which should do away with the necessity for water-tight doors in order to give proper convenience to engineers, and at the same time ensure sufficient subdivision. This appears to me to point to the fundamental nature of this question of water-tight doors; it even seems to me to affect the question of whether a ship should have two, or three, or more screws, so that, while it may be possible that in adopting more than two screws there is some sacrifice of efficiency in propulsion, still it may be desirable to do that, in order to obtain the efficiency of safety, which is, I think, quite as important. The question of existing ships can be dealt with, as Sir William White has pointed out, in so far as the structural arrangements admit; that is to say, if it is possible to shut a door the commander of a ship can order it to be shut. In many cases it is not possible to have it shut, because that is the only means of communication with the compartment. The horizontal armoured decks which are part of the fighting resistance of our ships, it seems to me, bar the question of doing away completely with doors through transverse bulkheads outside the machinery space, unless we are prepared to take an equal number of doors through the protective deck itself; and then again comes in this question of compromise. Is it better to run the risk of having these doors in the protective deck open rather than to have the doors below the protective deck open in a corresponding position? The question of the actual results of running a ship with compartments completely separated is not a new one. I think it is within the memory of a great many here that among the earliest ships that had complete bulkhead subdivision without having doors in the bulkheads were two of the large Atlantic liners. In that case there were three boiler rooms, each completely separated from the other, and an engine room in which there were two engines subdivided by fore and aft bulkheads. Now, these vessels were successfully run without doors in the bulkheads, and they were run under conditions which I think are not likely to be exceeded in stringency even by war conditions. These ships were in the first place designed to be run under those conditions, and therefore every precaution was taken to facilitate communication. There were hydraulic hoists or lifts situated so that the engineers had not the physical exertion of going over the bulkheads, and the ships were successfully worked with these arrangements. I think that is an important factor, because in the Atlantic trade, as everyone knows, the driving is exceedingly hard, and the conditions as stringent as are likely to exist even in war time. I am glad to see that the gentleman who was responsible for the driving of those ships, at the time I refer to, is in this room, and if he can be induced to say a word or two upon the question of how a ship can be run without holes in her bulkheads, I think it would be of interest to the meeting. There is one more point which I should like to mention, and that is that, it seems to me the question of putting boilers and engines into one compartment does not completely satisfy the whole of the necessary conditions. If possible it is desirable to have, not only the boilers, but the coals necessary for those boilers, in the same space that is bounded by the same transverse bulkheads, and then, as Mr. Martell has pointed out, if you have a sufficient number of these bulkheads in a similar way to what the Atlantic liners have, you may be quite satisfied to let them be filled, one by one, and take your chance with each compartment on its own merits. There was a question raised by Admiral Wilson, that communicating pipes between the sides of the ships are desirable. I pointed out, in a paper which I read eighteen months ago at Southampton, that that was a thing which could be adopted very easily, both in war and in merchant ships. I think it could be readily done by merely connecting the wing compartments above

the protected deck; for instance, with the double bottom, and having the compartments of the double bottom between the two frames made water-tight, so that the water could flow right through from side to side. It would be desirable, however, to have some controlling flap or valve in between, because, if you do not have that, and the water gets in too freely from side to side, and you have many of those compartments filled, you would have a considerable loss of stability; but if the water was restrained, so that it flowed freely from side to side, then the object aimed at would be fully attained. You would not have a list on the ship caused by damaging one side, because the other side would be immediately filled, and the loss of stability that would be inflicted would be compensated for if the water could not flow too freely from side to side.

Mr. E. G. Gearing (Member): My Lord and Gentlemen, I have been referred to as having done what I almost thought was impossible, and that is, to drive a ship across the Atlantic, under the same conditions as a warship, without bulkhead doors. As Mr. Biles has said, these ships had three compartments; the engine-rooms were intact from the first boiler-room, and the other two boiler-rooms were also separated. I almost think, in spite of what Admiral Fitzgerald has said, that I did an heroic thing because I was offered these doors and would not have them. I went even further, and when they were talking of piercing these bulkheads (although I was told I did not know what was good for me) I said: "If you leave that bulkhead-door aboard this ship I'll throw it overboard when we get clear of the land," as, I maintain, that the ship is better with the bulkheads intact. I have heard it said in case of panic: "How is a man going to get through?" A panic in the stokehold, I think, is best localised; you had better have it by itself; you do not want to communicate it, because the other men can get on with their work without being bothered with what the fellows have got wrong next door. On one occasion—which I gather from what Admiral FitzGerald has said is similar to his experience—out of eight pumps which I had available for feeding nine boilers (and each of these boilers would give a good 2,000 H.P. and have averaged that across the Atlantic) I had only one available for feeding the boilers, I am proud to say that my staff did not require the ship stopped. We kept the ship going at a rate of 10 or 12 knots, and we had one pump for a considerable time—that was a 6 in. double action pump—to feed those nine boilers. The only communication between the stokehold and the engine-room was by voice-pipes, and I can tell you we had a pretty lively time of it, because I had no sooner done answering one whistle than another one was sounded. "What is it?" "Short of water in the forward stokehold," &c., &c.—I need not elaborate it. My point is that we did not stop the ship; we kept her going at a rate of over 12 knots under those conditions. On another occasion the main feed pipe burst. We did not stop the ship on that occasion. That same ship, not long after I left her (I made several voyages in her), had a very serious accident, and I think that she is about the only ship that had such an accident and came into port, and also about the only ship that had not a bulkhead between the engine-room and the stokehold pierced. There is one little point I would like to mention, with all due deference, and that is, the way we got over this difficulty of communication was by simply dividing the engineers into groups. I had rather a large staff—there were 25 engineers beside myself, including electricians, and 150 odd greasers, stokers, and trimmers. The engineers were divided into simple groups, so that, whenever an engineer went into the stokehold—supposing the engineer in charge went into the stokehold—he left behind him his immediate junior in rank, and there was no difficulty about who took charge. Of course when the man in charge was away he was superseded by another, and he also, when he left, was superseded by his next in rank. We had—in the Navy it is a different system—what we call three seconds, six thirds, and six fourths, so that

there was always an engineer of equal rank. The engineer in charge of the engine-room ordinarily was a third, and the engineer in charge of the stokehold was a third. It seems to me, with some such simple arrangement of organising the men, that the engines can be driven, and at high speeds too, without piercing the bulkheads.

Mr. P. S. Pilcher (Associate): My Lord and Gentlemen, on reading through Lord Charles Beresford's paper a very simple type of doors suggested itself to me, to lessen the danger of water-tight doors, which would, I think, be practicable in some cases. The door is so made that a rush of water through the door aperture would necessarily close the door if it was left open when an accident occurred. These diagrams on Plate XXXII. lilustrate the system. If it were made as in Fig. 1, the so-called door consists of two doors placed at an angle to each other. They should be so made that each leaf could be turned right back so as to secure a clear gangway when necessary in port. Clips (as in Fig. 2) would be fitted so that the door could be kept shut in either extreme position. Figs. 3 and 4 show other ways of accomplishing the same object. The clips would be fitted for securing the door in either extreme position. Balance weights should be fitted in all cases so as to keep the door from banging about when the ship rolls. In the case of a compartment being flooded any of these doors closing automatically a man could always go down on the dry side of the bulkhead and secure the clips afterwards. These diagrams show the doors in section looking from above.

Admiral the Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S. (Vice-President): My Lord, having Admiral Colomb's permission, and as I think probably the meeting may rather have gathered from his speech that the naval officers were not sufficiently early introduced to the designs of ships, I may remind the meeting, and perhaps also my gallant friend, that Sir William White is not autocratic. He designs the ships both for the dockyard and also the contract ships that are to be built. His technical immediate superior is a distinguished naval officer—Sir John Fisher, and Sir John Fisher is as much responsible for the designs as Sir William White. Sir Frederick Richards, the First Sea Lord of the Admiralty, is also a seaman of distinction, and he has also to sign every design before it is sent to the dockyards or the contractors. It may be possible that more accurate naval supervision is necessary, but it seems to me, if Sir Frederick Richards and Sir John Fisher do their duty, as I do not doubt they do, there are, from the instant the design is completed on paper, accurate naval supervisors who have full powers to alter any arrangement of the ship, though, of course, they probably abstain from doing so, and they will not put their name to the design unless it meets with their approval. I thought it right to correct my gallant friend, Admiral Colomb, by pointing out that there are naval officers whose responsibility is complete—naval officers of great experience, or they would not hold the posts they do hold—that is to say, Controllers of the Navy. The signature of the First Sea Lord of the Admiralty assures the public that the Navy are satisfied with the designs, and the ships which those designs are calculated to produce. I know we like to be accurate here, and I received my gallant friend's permission to make that correction, which I do with some little experience of the mode of conducting business at the Admiralty.

Mr. John Thom (Member): My Lord and Gentlemen, I am very pleased that Mr. Pilcher has introduced the question of improvement in water-tight doors. I do not think the gentlemen who have spoken have suggested any improvement in the doors, although it was suggested that such was necessary in the papers read. I think we ought to know what other people are doing in this question, as I feel certain there are many better designs than those adopted by the Admiralty and the Mercantile

Marine. A model is on the table of a door adopted by the Spanish Government in the three first-class cruisers built at Bilbao. This is a patent of Mr. James S. Clark. On page 165 of the paper read by Lord Charles Beresford, it is stated that the principle should be enforced that the door be released or secured by one movement, and the door that I have just referred to is released or secured by the raising or the lowering of a lever or handle. The raising of the handle moves the whole door backwards, releasing the catches or clips, thus dispensing with the large number of handles that are necessary for the securing of the present style of door. The hinges of the door slide in a dove-tail groove, the hinges being worked by a shaft. This shaft may be carried to the deck above, and serves as an indicator to the officer on deck when the doors are opened or closed. If desired, the door may also be opened or locked from the deck above. I might mention that these doors were fitted not only on the bulkheads of the cruisers mentioned, but also to all of the magazines, and, on account of the facility with which these doors could be worked, it was afterwards decided to fit doors between engine-room and boiler-room. The sketch Fig. 1 consists of two doors, one hinged on the one side of the bulkhead, and the other on the other side. The distance between the hinges can be increased, so that one door could be at one end of a short passage and the other at at the other end, if desired. The door A is connected to the door B by by a link L, which keeps the doors in the same relative positions as shown in the sketch. When they are connected, and the guards fixed on bulkhead at outer edge of door, and also at top and bottom of door, then no communication can be made between compartments, the action of opening the one door closing the other. By drawing back and opening door B, the action closes door A on stop at A[1] on centre of bulkhead, as shown by dotted lines. Entering between the doors, and pushing door A before you, closes door B behind you, similarly to a segment of a turnstile. This arrangement of door would close automatically by the pressure of water in either compartment. It cannot be left in a position to give free access of water from one compartment to the other. After the door is closed by the pressure of the water in the one compartment, it will always be possible to get between the doors from the other side and fasten up the clip, as usual, on india-rubber joint at bulkhead. This door does not require to be worked from deck, as it cannot be left open when connected in this manner by link L.

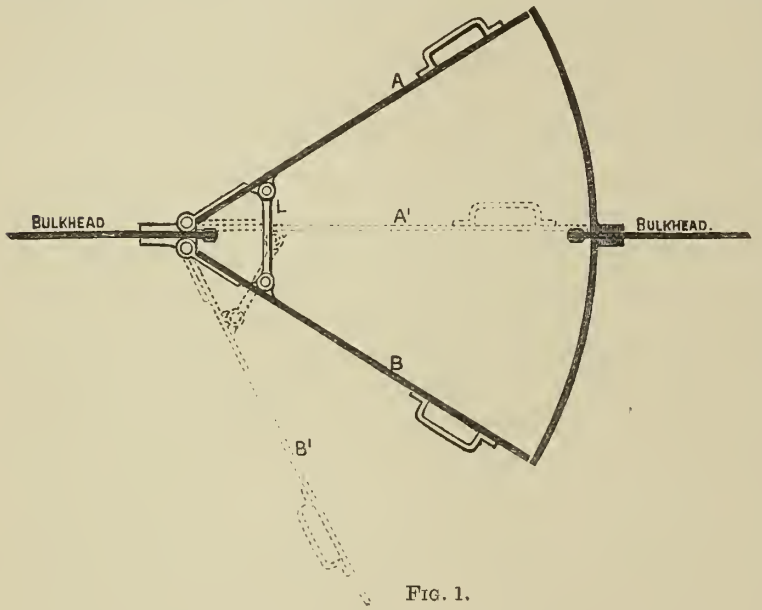

Fig. 1.

Mr. B. Martell (Vice-President): My Lord, may I be allowed to say, for the information of the members here, that there are four models here of improved doors. I think the members should know that, in order that they may have an opportunity of looking at them. Some of them are, in my opinion, far superior to the common ordinary water-tight doors usually fitted.

Rear-Admiral C. C. P. FitzGerald (Associate): Perhaps, my Lord, you will allow me to say this: I fear I was misunderstood when I dissented from Mr. Martell in his statement of the broad fact that the safety of ship and crew was of more importance than the convenience of the departments. As I said in my remarks, I recognised that as a self-evident truism; I merely wished to dissent from it in the way he put it. It is a question of the amount of safety you can get (there is no such thing as absolute safety) *versus* convenience of departments, which, as I pointed out, means the fighting efficiency of the ship. I never meant to controvert the assertion of the general principle which Mr. Martell, with his usual eloquence and powers of illustration, has so ably put before us.

Captain the Right Hon. Lord Charles Beresford, C.B., R.N. (Visitor): My Lord and Gentlemen, I think, from the debate, that I may be satisfied with the result of having brought this paper to your notice. The preponderance of opinion, I think, is on my side: anyhow it is a perfect discussion on a matter on which there are very different opinions, and that, I think, is for the good of the Service, and the good of the State. I will, if you will allow me, shortly notice the remarks made on my paper. First, Admiral Wilson on the great principle generally agrees with me, but he brought forward a most interesting question, which is that of the necessity of having one side of the ship in intercommunication with the other, in the event, we will say, of the water getting into the starboard boiler-room or engine-room, and giving the ship a great list, which would put her in danger, and certainly prevent her from fighting her guns. Beyond saying that I think Admiral Wilson agreed with me I will not dilate further on his remarks. Now I come to Sir William White, and I wish to say how delighted I am to see him well and cheery again, and also to find that he has not lost any of his old debating skill. There is no question about it, he would be a great ornament to the House of Commons. There were several remarks which he made with regard to my paper. He first made out that there were 208 doors, and I only wanted to do away with 19. That looks, on the face of it, a very few, but those 19, I tried to explain, are in the belly of the ship. They are in the engine and boiler-rooms, or thereabouts, and if that portion gets damaged, if you have your starboard engine-room pierced, and the water runs right across into the port engine-room, your ship is out of action altogether. You cannot pump the ship out, nor proceed with one screw, and I believe if you have doors there you invite the accident to occur. He spoke also as to the weakening of the bulkheads. I thought they were too weak, and I merely suggested that I thought they were too weak. I am not a constructor, and I wanted his advice and assistance on the matter—are they, or not, too weak? I think he conclusively proved—to my satisfaction certainly—that I was wrong. He seems to think they are strong enough, and certainly the argument which he adduced from the *Howe* was an excellent one. Then he spoke about the captain ordering the doors to be shut. With regard to that, how many times has this thing occurred? According to my estimate we have expended some three millions of money, and I do not know how many lives and ships, on account of having these doors. Whenever the doors are open and an unforeseen contingency occurs, those ships are lost, and therefore I maintain the argument is all on my side, and not on Sir William White's, with regard to the captain being able to shut the doors. He can shut the doors, no doubt, but the doors are never shut when the unforeseen contingency happens, and the mere fact of the door being there at all is what has lost the ship. He said it was a twenty years' story, and he brought up the case of the *Vanguard*, and said there was a lesson to be learned there, and he was learning it. From my point of view he has not learnt it yet. Then there is the question of the demand for more doors. I quite agree with that. I think that has very much come from my own brother officers; but I venture to disagree with them, and I do

not think those officers who hold opinions like Admiral Fremantle are right—certainly they are not right in the circumstances of the cases, as they have occurred, because the ships with doors, when they have been struck, have invariably gone down.

Admiral FitzGerald: The *Camperdown.*

Lord Charles Beresford: That is an argument on your side, I admit. As far as the debate went, and from conversations, and letters I have received, there are quite as many people of my way of thinking as on the other side; and after those interesting circumstances which have been narrated by a gentleman connected with the great steamship lines (Mr. Gearing), I think there are more practical men of my view than on the other side. Sir William White hinted that I knew about the *Magnificent.* I do not suppose there is a man fore and aft the British Empire who knows more about the *Magnificent* than I do, for I was absolutely "built in her." I saw the first bit of steel laid down, and I was in her until the day the pennant was hoisted, and I'll pass an examination as to the construction of that ship with any man in the Kingdom, so that I certainly know what I am talking about with regard to that ship. There was another point which Sir William White drew attention to. He rather laughed at my idea of the "quick passage"; my small scuttle at the top of the bulkhead. What I meant was, that that was quicker for the engineers than going right up on the deck, along the deck, and then down to another compartment. I should be glad to take part in the obstacle race he suggested, but that is not intended; I did not intend it as an obstacle race, but that there should be a means of getting through the bulkhead which is safer than the present means. Sir William White also said that these great risks which I conjured up did not exist. Now, I must join issue with him there, because, after all, these great risks are not to our friends who enable us to fight these ships by their cleverness and their brains, but to us. We are in the ship when these accidents occur, and when the ships go down bottom up, or some other way, the constructor is sitting at home, and the only risk he has is to explain why the ship did go down. In the case of the *Victoria* the explanation was very ample and very full; but the risk that my good old friend ran was not very great because he was in the curious position of prisoner, witness, judge, and jury all in one with regard to the loss of that ship. Therefore the risk was not very great in that case. Now, I must turn to my gallant friend below me (Admiral FitzGerald), and I must remind this company that both my gallant friend and myself come from the same country—that is, Ireland—and, therefore, it was hardly within the bounds of possibility that my gallant friend would have agreed with me under any circumstances whatever. He quite misunderstood me as to the small hole at the top of the bulkhead. What I wanted it for was quick verbal communication, so that the engineer can shout out to his men if the eccentric band is hot, or if a fire is bright, which is a different thing to being able to pass through a bulkhead with a great door which must be a weakness to the ship. It is the quick verbal communication that the engineer wants. He does not want a voice-tube. There is a very good instance given (I do not know whether it was my gallant friend or not) with regard to the voice-tube. There was a captain who was not very agreeable, and a commander who was equally disagreeable. They were talking through the voice-tube and could not understand each other, and at last the captain said: "I do not want a d—— fool at the end of the tube," and the commander replied: "I would not have him, sir, he is not at this end." The gallant Admiral who spoke on this point I must rather fall foul of, if he will allow me. He said that in the *Centurion* he had the doors closed, and then said to his commander and the engineer officers: "I wonder if these doors are safely closed and secured?" and he sent for the petty officers and said: "Go down and let me know if these doors are properly secured," and the same men came up and naturally reported they were so.

Admiral Fremantle: Lord Charles has made a very good story of it, but he entirely misunderstood me, or failed to hear me. I said to the captain beforehand, "Now we are going to close water-tight doors, and I have grave doubts as to whether they are closed properly or not," and I sent privately to the fleet engineer and to the first lieutenant, who came up to me without knowing in the least what was going on, and the instant the water-tight doors were reported closed they ran down to see whether they were properly closed. They had nothing whatever to do with the closing of them, and were independent authorities, and they reported upon the petty officers, and the petty officers did not report upon themselves.

Lord Charles Beresford: I beg the gallant Admiral's pardon. I certainly understood him that the petty officers went down. Then reference was made to naval officers having something to do with the building of ships, the general design. I do not think it appears to be generally known now that naval officers have a considerable deal to say to it. Of course they are not experts, but they are rather interested in the matter, because the question came before the Board that I had the honour of belonging to ten years ago. You remember before that, ships were built 2 ft. over their draught. That was not the constructor's fault at all. You never did bring the constructor and the naval officer together before the time I said—it is quite new. In 1886 or 1887 there was what was called the shipbuilding circular, which was a thoroughly business-like idea, and which I think emanated from the brain of the present Controller. But I remember it was one of those subjects on which I was considered rather inconvenient in the Admiralty. People say the experts do not agree. That is so, because we never boil our ideas down together. In the House of Commons people do not agree; they do not agree when a Bill or motion is brought before the House of Commons. Every one of the 600 members gets up and endeavours to knock some hole in it, but eventually they make something out of it; and if you put the experts together they will knock something out of it. You call experts —one man wants coal endurance, another big boilers, another heavy armour, another heavy armament, and they all disagree as to what is the best form of fighting ship; but put them together, and when you have put a dozen opinions together, send for the constructor, and tell him to build a a platform to float it, and the result of it all is, as in the *Royal Sovereign* class, that he could not build what the seamen wanted under 17,000 tons, so they had to give way with regard to the coal endurance, and the boiler power, and other things, until they got an excellent ship. That is a very good plan, and ever since that circular we have had our ships built to carry what they were intended to carry, and at the draught they were originally intended to be. As far as the Admiralty goes in that particular they have not a boat better built, nor can the ships be built on more business-like lines. Gentlemen, I think I have answered most of the opposition to my paper. I hope and trust the paper will do good. I feel very strongly on the point, and I cannot help once more referring to the fact that, as events have proved, when ships have been damaged and their doors are opened they have generally capsized. I may say with regard to the loss of the *Victoria*—it is a curious thing—at the time I was captain of the *Undaunted* in the Mediterranean Fleet, I was subject to the orders of my Admiral, and I had to obey orders, and not to give them; but I thought so strongly of those light-ended ships in comparison to the ships they might meet that I wrote a letter to my Admiral, and apologised for interfering with a matter which was not mine, and saying I hoped he would forgive me and excuse me. I said: "If these ships get wounded, and get water in them on the protective deck, they will go down bottom up." That was eighteen months before the *Victoria* did go down bottom up, and she got the water in the same way that those ships would get it by the influence of shot and shell, because her scuttles and her doors were open. Mind you, it is only in close action.

I always distrusted those ships, and I merely state this to show that I have thought of these things for a great number of years. Gentlemen, I have to thank you very much for the kind way in which you have listened to me.

Colonel N. Soliani (Member): My Lord and Gentlemen, when I prepared this paper I felt I was taking coal to Newcastle, but, supported as I was by the kind encouragement of Sir William White, I wrote it with the view that the paper would give occasion to a thorough discussion of the whole subject. Moreover I had in mind the pleasure that it would give me to come here amongst you. I am greatly indebted to the Council of the Institution, who, although there was another paper, that of Lord Charles Beresford, dealing with the same subject, did me the honour of accepting, all the same, this paper of mine, following in so doing the custom of their traditional courtesy to foreign members. After the able and lively discussion that there has been on the subject by various members, it would be preposterous on my part to add other remarks, and I will only ask your permission to say a few words. First of all, I wish to express my thanks to Sir William White for his kind remarks on my paper. In regard to the view expressed, and generally accepted, of having as few doors as possible on board ship, I think that the arrangement of the engines and boilers has on this point an important bearing. If the engines are, as usual, at the after end of the ship and all the boilers are forward, the control of the chief engineer over the machinery departments, and the intercommunication between engines and boiler-rooms, cannot be easily exercised unless there are doors in the bulkheads separating the various compartments; but if, instead, the engines are in the centre of the ship, and the boilers are divided into two main compartments, one aft and one forward of the engines, then both the control of the chief engineer and communication from the engine to boiler-rooms, may be efficiently and rapidly exercised by the engine-room staff from the engine-room itself, through self-closing scuttles of a few inches diameter, and the water-tight doors can be dispensed with. Through these scuttles the chief engineer can, in fact, easily see everything going on in his own department, and give his orders and exert his influence, in case of need, wherever required, without leaving the engine-room. But whatever the number of doors may be on board a ship, the really important point, in my opinion, is that, when the ship is at sea only the doors that need be open shall be kept open, and all the others shut. This object, I think, can be better carried out in an efficient way if there be on board a special officer to whom the service of the water-tight doors be entrusted. Of course I do not mean to say that the naval officers and engineer officers do not exercise care on this point, but I mean that, they have so many other things to think of that they may overlook this important matter. It is not so if there is an officer on board the ship who has little else to do, and has special charge of this important duty. In the Italian Navy, for instance, we have on board our big ships a young naval architect, who has principally to act as an A.D.C. of the captain of the ship for any co-operation he may want. To give to this young officer some permanent duty to perform, such services as that of the water-tight doors are entrusted to him, which are akin with his profession, and which he is well suited to perform, and does perform well. Apart from this consideration, the measure adopted of having young naval architects on board big ships, has the advantage of affording these officers means to acquire a full knowledge of the requirements of the ships in the various conditions of service; because, though it is very good to read books, and hear the opinions of experts, it is much better when one can actually see for one's self in effect, what are the exigencies of life on board ship. There is also the interchange of ideas between naval officers and naval architects, as hinted at by Admiral Fremantle, and which is certainly advantageous both to the officers and the service. These are the few words I had to say, which, I think, agree on the whole with the ideas expressed by the

various speakers. Now, my Lord and gentlemen, I have to thank you very much for the cordial welcome you have given to my paper.

The President (the Right Hon. the Earl of Hopetoun, G.C.M.G.) : Gentlemen, I feel quite certain it is your wish that the hearty thanks of this meeting be tendered to Lord Charles Beresford and Colonel Soliani for the two very interesting papers which they have read to us.

SOME GEOMETRY IN CONNECTION WITH THE STABILITY OF SHIPS.

By J. Bruhn, Esq., D.Sc., Member.

[Read at the Thirty-seventh Session of the Institution of Naval Architects, March 25, 1896; the Right Hon. the Earl of Ravensworth, Past President, and Vice-President, in the Chair.]

The question of the stability of ships in still water is almost purely a geometrical one. Gravity, it is true, is an important factor, but it enters in general into the investigations in the nature of a constant. Geometrical principles are, as it were, at the very root or the foundation of the question. The shipbuilders of ancient times had, without doubt, no knowledge of Euclid's theorems, still they did know the importance of the geometrical ratio of beam to depth, as far as the stability of their crafts was concerned. It was a long step from this vague knowledge, that breadth is beneficial to stability, to the discovery of the metacentre. The importance of this point with regard to the stability of ships has its origin in the fact that, the distance between the centre of gravity of the ship and the metacentre enables us to obtain the righting arms for small inclinations; or the length usually designated G M gives us the rate of increase of the righting arm in point of the angle of inclination. It is on this account only that the metacentre is of direct practical importance, and it would appear to be more natural, to beginners at least, to look upon G M, not as a length, but as a rate, which enables us to determine the direction of the curve of stability at the origin, or at the upright position. The next step in advancement of our knowledge of the question was the determination of the complete curve of righting arms, for a constant displacement. This was almost as important a step as the discovery of the metacentre. The construction of the curve of dynamical arms and the calculating of cross curves of righting arms were important advancements, though not in comparison with the two former discoveries.

From a geometrical point of view the practical question of the stability of ships in still water may be said to have been solved, when we were in a position to construct the above-mentioned curves. We were then able to determine the righting arms for any displacement, any inclination, and any position of the centre of gravity of the ship. Further geometrical investigations were of interest only in so far as they tended to

broaden our view of the subject, and lessen the labour involved in actual calculations, and in this way the following geometrical problems may perhaps be of some value.

To Construct Geometrically a Set of Cross-Curves of Stability for Inclinations from 90° to 180°, when we know the corresponding Curves for Inclinations from 0° to 90°.

If we take the complete form of a ship or other floating body, and suppose a perfectly elastic membrane to be drawn over it, then we know that this enveloping surface will have no re-entering parts, and that it is the surface of least area within which the body in question can be placed. All centres of buoyancy and flotation must be inside this imaginary membrane; in fact, all the surfaces of buoyancy and flotation lie completely within it. Let Fig. 1, Plate XXXIII., represent a floating body. W L is the plane of flotation, and B the corresponding centre of buoyancy. Let b be the centre of gravity of the volume of that part of the body, which is out of the water. It is evident that the common centre of the total volume lies on the line B b. Let it be at C, and let the total volume be Δ, and the volume below W L be D. The volume above W L is consequently $\Delta - D$. It has been proved that

$$D \times BC = (\Delta - D)\, bC. \qquad (1)$$

This equation shows that for each centre of buoyancy below W L there is a corresponding centre of the part above the water, and the line joining these two points is divided in a constant ratio by the centre of bulk C. In other words, there is for each surface of buoyancy a corresponding one, which is similarly situated with regard to the centre of bulk and is similar, in the inverse ratio, of the volumes of displacement. When the displacement is approaching zero, the surface of buoyancy corresponding to B clearly approaches the surface of the afore-mentioned imaginary membrane. When the volume in the water equals that out of the water then the two similar surfaces coincide. When the body comes near total immersion then the surface of buoyancy becomes very small, or approaches the centre of bulk C. It will, however, in form be similar to the shape of the ship, or rather the imaginary membrane, but it will be inverted.

Let C Z be the perpendicular from C on the vertical through B, and C Z_1 the corresponding length for b, then it is evident, from similar triangles, that—

$$D \times CZ = (\Delta - D)\, CZ_1. \qquad (2)$$

If we assume that C is the centre of gravity of the ship, then the above shows that the righting moment, for a displacement of D and an inclination of, say $\theta°$, is equal to the righting moment for a displacement of $\Delta - D$ and an inclination of $180° + \theta°$. When we are dealing with a body like a ship, which is symmetrical with regard to a

middle line plane, then the righting moment at $180° + \theta°$ is equal, with opposite sign, to the righting moment at $180° - \theta°$. Call $C Z_2$ the righting arm at an inclination of $180° - \theta°$ and a displacement of $\Delta - D$, then

$$D \times C Z = -(\Delta - D) C Z \qquad (3)$$

This enables us to calculate the cross-curve of righting moments for an inclination of $180° - \theta°$, when we know the corresponding curve for an inclination of $\theta°$. There is a very simple geometrical connection between the two curves. Let O P A (Fig. 2, Plate XXXIII.) be a cross-curve of righting moments corresponding to an inclination of $\theta°$, and assuming the centre of gravity to be at the centre of bulk. Draw a curve A Q O symmetrical with O P A, with regard to T, the middle point of O A. This curve is the cross-curve of righting moments for an inclination of $180° - \theta°$, because the ordinate S Q at a displacement of O S, or $\Delta - D$, is equal, with opposite sign, to the ordinate R P, at a displacement of O R or D, the length O A being equal to Δ.

If we are dealing with the cross-curves of righting arms, then a similar construction may be used. Let A P (Fig. 3, Plate XXXIII.) be such a curve for an inclination of $\theta°$. O R is equal to D, and O A equal to Δ. Make O S equal to $\Delta - D$ or R A; draw lines through S and R at right angles to O A; make $R P_1$ equal to R P with opposite sign; draw $A P_1$, and continue it until it intersects the line through S in Q. Q is a point on the cross-curve of righting arms for an inclination of $180° - \theta°$, because

$$\frac{S Q}{A S} = \frac{R P_1}{A R} = -\frac{R P}{A R} \qquad (4)$$

or —

$$S Q (\Delta - D) = -D \times R P \qquad (5)$$

Other points on the curve A Q may be found in the same way. We can, therefore, in a few minutes construct all the cross-curves from 90° inclination to 180°, when we have the corresponding curves for inclinations from 0° to 90°. The cross-curve for 90° will be its own reciprocal. It may often be useful to know the direction of the tangent at A to the curve A P (Fig. 3), in order that we may determine on which side of the base line the curve lies. This is sometimes difficult, owing to the curve crossing the base. Let α be the angle which the tangent at A makes with A O, tan α will be the ratio of $\frac{R P}{A R}$, when R approaches A; we have, therefore—

$$\operatorname{Tan} \alpha = \underset{A R = 0}{\frac{R P}{A R}} = -\underset{A S = \Delta}{\frac{S Q}{A S}}$$

Let $S_1 Q_1$ be the righting arm for no displacement, and an inclination of $180° - \theta°$. Set it off from O with opposite sign. Join the point Q_1 thus found with A, this line $Q_1 A$ will be the tangent required. The lengths of $S_1 Q_1$ can in general be found by drawing a tangent to the midship section of the ship. In the foregoing it has been

assumed that, the centre of gravity of the ship coincides with the centre of bulk or volume. In general it will not do so, but in recording curves of stability it may perhaps conveniently be assumed in that position, as in that way it is to some extent eliminated, and the effect of variation in form is better seen.

To Determine the Direction in which the Centre of Buoyancy Moves when the Ship is Inclined in a Given Direction.

Let B, Fig. 4, Plate XXXIV., be a centre of buoyancy, and let A B be a line parallel to the axis about which a small inclination $d\,\theta$ takes place. Call the plane which is perpendicular to B A, and contains the line $B\,B^1$, the plane of inclination. Let B move to B_1, when the ship is inclined through an angle $d\,\theta$. $B\,B^1$ or $d\,s$ is the projection of $B\,B_1$ on the plane of inclination. Call B^1B_1, $d\,\sigma$, and the angle $B^1B\,B_1$, η. If we refer the line of flotation to an axis of X in its plane, passing through the centre of flotation and being parallel to B A, then we know, when y is the ordinate of the line of flotation, and V the volume of displacement, that

$$V\,d\,s = \frac{1}{3}\int y^3\,d\,x\,d\,\theta = I\,d\,\theta \qquad (1)$$

$$V\,d\,\sigma = \frac{1}{2}\int y^2\,x\,d\,x\,d\,\theta = P\,d\,\theta \qquad (2)$$

Where I is the moment of inertia of the plane of flotation and P the product of inertia of this plane referred to a pair of rectangular axes passing through its centre, the one of them being the axis about which the moment of inertia is taken, we have further—

$$\tan\,\eta = \frac{d\,\sigma}{d\,s} = \frac{P}{I} \qquad (3)$$

The ellipse of gyration of the plane of flotation may be proved to be similar to the indicatrix for the corresponding centre of buoyancy. Hence let Fig. 5, Plate XXXIV., represent either of these ellipses. D O D_1 is a line through O, the centre of buoyancy corresponding to the upright position, and parallel to the axis of inclination. We can, from this ellipse, determine the radius of curvature of the real curve of buoyancy; the radius of curvature of the projection of this curve on the plane of inclination; the radius of curvature of the intersection between the plane of inclination and the surface of buoyancy; the direction in which the centre of buoyancy moves; and a length which we might call the radius of torsion. Draw a tangent A B parallel to the axis of inclination. We then know that the real radius of curvature varies as the square on O B, and the radius of curvature of the projection of the curve of buoyancy on the plane of inclination varies as the square on O A, the perpendicular on the tangent. This radius is, of course, the length usually designated B M. The radius of curvature of the normal section made by the plane of inclination

will vary as the square on O C, C being the point where O A intersects the indicatrix. The moment of inertia of the plane of flotation about an axis parallel to D D_1 will vary as the square on O A, and the product of inertia of the same plane, referred to the same axis as before, will vary as the product of O A and A B. Hence we have, if β is equal to the angle A O B, that—

$$\text{Tan}\,\beta = \frac{AB}{OA} = \frac{AB \times OA}{OA^2} = \frac{P}{I} \qquad (4)$$

This proves that the angle η (Fig. 4) is the same as the angle β (Fig. 5), or O B is the direction in which the centre of buoyancy moves when the tangent at B is parallel to the axis of inclination. We have that—

$$\text{Tan}\,\eta = \tan\beta = \frac{d\sigma}{ds} = \frac{\left(\frac{d\sigma}{d\theta}\right)}{\left(\frac{ds}{d\theta}\right)} = \frac{\frac{P}{V}}{\frac{I}{V}}$$

As $\frac{ds}{d\theta}$ is equal to $\frac{I}{V}$, it follows that $\frac{d\sigma}{d\theta}$ is equal to $\frac{P}{V}$. This latter quantity is clearly a length which gives the rate, in point of θ, at which the centre of buoyancy moves perpendicular to the plane of inclination, just as $\frac{ds}{d\theta}$, or $\frac{I}{V}$, gives the rate at which it moves parallel to that plane. It might be called the radius of torsion, and it will vary as the product of O A and A B (Fig. 5).

Lines of Curvature and Geodetic Lines as Curves of Buoyancy.

Let $\frac{d\sigma}{d\theta}$ have the same meaning as before. When it is zero, then we know that the product of inertia of the plane of flotation is zero, and the axis of inclination must be parallel to a principal axis of the indicatrix. If we incline the body in such a way that $\frac{d\sigma}{d\theta}$ is always zero, then the curve of buoyancy is a line of curvature. It has the property, as shown by Dupin, that consecutive normals, which have their feet on it, intersect each other. For each centre of buoyancy there are, of course, two lines of curvature at right angles to each other and corresponding to the principal axis of the indicatrix. It is a well-known theorem in solid geometry that, if a point on a surface moves along a line of curvature, then the centre of curvature corresponding to this line (not of it) moves along a geodetic line on the surface of centres. A geodetic line is a line on a surface, which has no curvature in the surface, and consequently is straight if the surface is plane. It is also the shortest distance on the surface between any two points. We have therefore the theorem that, when the centre of buoyancy moves in a line of curvature on the surface of buoyancy, then the metacentre moves in a geodetic line on the surface of centres.

Suppose a synclastic surface, or a surface without any re-entering parts, to roll on a plane without spinning. The point of contact traces out one curve on the plane, and one on the surface. Taking a small portion of the surface round a point of contact, it is seen that the part of the curve on the surface, lying within the small portion considered, coincides with the corresponding part on the plane. Hence the curvature in the plane and in the surface is the same for corresponding points on the two curves. The curve on the plane can therefore be rolled, or wound, on to the one on the surface by merely bending the plane across certain lines, or the operation can be performed without altering the curvature of the curve in its own plane, or in the surface produced by the bending of the plane. Therefore, if the curve is straight on the plane, it will be geodetic on the surface, and *vice versâ*. Suppose a floating body to be inclined in such a way that the centre of buoyancy is in a given vertical plane, and that no spinning is allowed. Suppose, further, a horizontal plane to be held, touching the surface of buoyancy at the centre of buoyancy. The locus which this point of contact describes, when the body is inclined, will clearly be a straight line, viz., the intersection between the horizontal plane and the given vertical plane. Being a straight line on the plane, it will be a geodetic line on the surface.

We have, therefore, the following theorem. If a body rolls without spinning in such a way that, the centre of buoyancy is always in a given vertical plane, or moves always in a given direction, then the curve of buoyancy is a geodetic line on the surface of buoyancy. The converse of this proposition is clearly also true.

Relations between the Surfaces of Buoyancy and Flotation.

Let B (Fig. 6, Plate XXXIV.) be the centre of buoyancy, and y the centre of flotation. The volume of displacement is V. Let y_1, x_1, z_1 be the co-ordinates of y; y, x, z those of B. If we increase V by d V, we have—

$$(\mathrm{V} + d\,\mathrm{V})\, d\,y = d\,\mathrm{V}\,(y_1 - y + d\,y);$$

or, if the area of the plane of flotation is A, then—

$$d\,\mathrm{V} = \mathrm{A}\, d\,y_1,$$

and we have –

$$\mathrm{V}\, d\,y + d\,\mathrm{V}\, d\,y = d\,\mathrm{V}\,(y_1 - y) + d\,\mathrm{V}\, d\,y_1,$$

or, neglecting small quantities, we get—

$$\mathrm{V}\, d\,y = d\,\mathrm{V}\,(y_1 - y).$$

This and the analogous formulæ may be written—

$$\mathrm{V}\, d\,y = \mathrm{A}\,(y_1 - y)\, d\,y_1 \qquad \frac{d\,y}{d\,x} = \frac{y_1 - y}{x_1 - x}$$

$$\mathrm{V}\, d\,x = \mathrm{A}\,(x_1 - x)\, d\,y_1 \qquad \text{or} \qquad \frac{d\,y}{d\,z} = \frac{y_1 - y}{z_1 - z}$$

$$\mathrm{V}\, d\,z = \mathrm{A}\,(z_1 - z)\, d\,y_1 \qquad \frac{d\,x}{d\,z} = \frac{x_1 - x}{z_1 - z}$$

These equations are only true when the ship is not inclined in any way, the draught and displacement only varying. They show that the locus of the centre of buoyancy is at any instant directed towards g, or the centres of flotation and buoyancy; trace, under the above conditions, the well-known curves of the master and his dog. The former being the master and the latter the dog. The corresponding loci for the centres of curvature of the projection of the curves of buoyancy and flotation on the plane of inclination have a similar connection, or a tangent to the locus of M (Fig. 6) passes through N, the centre of curvature corresponding to g. Let B M be equal to m, and g N equal to n, then we have, by Leclert's theorem—

$$n = m + \mathrm{V}\frac{dm}{d\mathrm{V}},$$

or—

$$\frac{dm}{d\mathrm{V}} = \frac{n-m}{\mathrm{V}}, \tag{1}$$

but—

$$d\mathrm{V}(y_1 - y) = \mathrm{V}\,dy; \tag{2}$$

hence—

$$\frac{dm}{n-m} = \frac{dy}{y_1 - y}. \tag{3}$$

Further—

$$\frac{dy}{y_1 - y} = \frac{dx}{x_1 - x}; \tag{4}$$

hence—

$$\frac{dm}{dx} = \frac{n-m}{x_1 - x}. \tag{5}$$

The direction of the tangent to the locus of M is given by—

$$\frac{d(y+m)}{dx} = \frac{dy}{dx} + \frac{dm}{dx} = \frac{y_1 - y}{x_1 - x} + \frac{n-m}{x_1 - x} = \frac{y_1 + n - (y+m)}{x_1 - x}.$$

As the co-ordinates of N are $y_1 + n$ and x_1, and those of M, $y + m$ and x, then it follows that, the motion of M will always be towards N, the tangent to the locus of M passing through the corresponding N.

A Corollary to Leclert's Theorem.

All the theorems regarding the curvature and the indicatrix of the surface of buoyancy are equally true when applied to the surface of flotation, the only difference being that, while in the former case the surface is always synclastic and the indicatrix an ellipse, it may in the latter case be anticlastic and the indicatrix a hyperbola or parabola. Let the ellipses with B and g as centres (Fig. 7, Plate XXXIV.) be the indicatrices for a centre of buoyancy and a centre of flotation respectively, or the projection of these curves on a horizontal plane. Let their major axes make angles α and β respectively with a fixed line, O X, parallel to the plane of inclination. Let m and n be the radii of curvature of the projections of the curves of buoyancy and flotation on the plane of inclination, and $\rho_l \rho_t$ and $r_l r_t$ the principal radii of curvature.

We know that

$$m = \frac{I}{V} = \rho_l \cos^2 \theta + \rho_t \sin^2 \theta.$$

$$n = \frac{i}{A} = r_l \cos^2 \theta \pm r_t \sin^2 \theta. \qquad (1)$$

where θ is the angle between the plane of inclination and the major axis of the indicatrix. Put $\theta = \alpha$ in the first equation and $\theta = \beta$ in the second equation, and we get the values of m and n corresponding to the same plane of inclination.

They are—

$$m = \rho_l \cos^2 \alpha + \rho_t \sin^2 \alpha.$$
$$n = r_l \cos^2 \beta \pm r_t \sin^2 \beta. \qquad (2)$$

From Leclert's formula we have—

$$n = m + V \frac{dm}{dV};$$

hence—

$$r_l \cos^2 \beta \pm r_t \sin^2 \beta = \rho_l \cos^2 \alpha + \rho_t \sin^2 \alpha + \frac{V}{dV} d\,(\rho_l \cos^2 \alpha + \rho_t \sin^2 \alpha).$$

For a plane of inclination at right angles to the former we have—

$$r_l \sin^2 \beta \pm r_t \cos^2 \beta = \rho_l \sin^2 \alpha + \rho_t \cos^2 \alpha + \frac{V}{dV} d\,(\rho_l \sin^2 \alpha + \rho_t \cos^2 \alpha).$$

Adding, we get—

$$r_l \pm r_t = \rho_l + \rho_t + \frac{V\, d\,(\rho_l + \rho_t)}{d\,V}.$$

This is a relation between the principal radii of curvature, corresponding to the usual form of Leclert's theorem which connects only the projections of the curves on the plane of inclination.

A Geometrical Construction for Finding the Length, n, or the Radius of Curvature of the Curve of Flotation from the Usual Information Given on Metacentric Diagrams.

Let O X (Fig. 8, Plate XXXIV.) be a base line of displacement, draw a curve M M_1, the ordinates of which are the radii of curvature of the curve of buoyancy. This can be done in the course of a few minutes, as everything is found on the metacentric diagram. Suppose we wish to determine n for a displacement Δ. Set off O B equal to Δ, draw B D parallel to the tangent at M, B M being perpendicular to O X, draw D C parallel to O X. C M is the length required. Because—

$$\begin{aligned} C\,M &= B\,M + D\,C \tan (< C\,D\,B) \\ &= B\,M + \Delta \frac{d\,(B\,M)}{d\,\Delta} \\ &= m + V \frac{d\,m}{d\,V} \end{aligned}$$

Other values may be found in the same way.

DISCUSSION.

Before the completion of the reading of Mr. Bruhn's paper,

Mr. Martell (Vice-President): Perhaps, my Lord, I might be allowed to ask whether sufficient of the paper has not been read to introduce it to the notice of the members. As the time is so late, and as so many wish to go, I would ask whether it might not be desirable to take the other portion as read. I merely put it to the meeting. I should not like Mr. Bruhn to desist from reading it without expressing, at all events, my own opinion of the value of this paper. There is no question it is very valuable, and shows a great amount of mathematical knowledge, and it could only be the possession of that knowledge which has enabled him to produce such a paper, which will be of great value when it is added to the Transactions of this Society. We all know the care he must have taken and the time he must have spent in producing this paper, and I can only say, as has so often been said before, we all feel the encouragement that should be given to the younger members of the Institution to come before us in this way. I am sure you will join with me in expressing our gratitude for the excellent paper which has been brought forward by Mr. Bruhn.

Professor J. H. Biles (Member of Council): Perhaps I may be permitted to endorse what Mr. Martell has so well said. I think Mr. Bruhn is a little unfortunate in having his paper put in competition with the necessity of dressing for dinner to-night. The value of his paper is not appreciated by reading it once. I had the pleasure of reading Mr. Bruhn's paper before he presented it to the Institution. He is an old student of mine, and I am able to follow his work very much more closely, probably, than many who hear the paper for the first time. I think it would be well just to say that this paper seems to me to be an instance of an exceedingly elegant way of showing, from a different point of view, what can be obtained from a geometrical consideration of the stability of ships. It is a subject that admits of elegant treatment at any time, and I think that the elegance of the treatment which Mr. Bruhn has given it, which is, as far as I know, completely original—it certainly is original on his part—has not been surpassed by any former investigators from the early time of Dupin, and that this paper is one of exceeding merit from that point of view. Its practical value is, perhaps, not as great as the practical value of some of the papers, but, as an exemplification of elegant geometrical work, I think it is a most valuable addition to the Transactions of this Institution.

The Chairman (the Right Hon. the Earl of Ravensworth, Past President and Vice-President): This is not the first time, gentlemen, that I remember a technical paper of this complexity; but, at the same time, the encomiums that have been passed on it sufficiently speak for themselves. Time is against us, and, on this particular day, we have always been in the habit of adjourning at an early hour; therefore Mr. Bruhn will not think there is any want of appreciation of his paper, and I hope he will be satisfied that time is the enemy on this occasion, and nobody else. I beg to thank him on your behalf for his very valuable paper, which you have had in your hands for several days; and, no doubt, many have appreciated its value, which I think we may take for granted after hearing the remarks of the authorities who have spoken upon it. This concludes the proceedings of the morning, and I can only say how much pleasure it gives me to meet so many old friends, and to receive the kind welcome which they have given me here.

Mr. Martell: My Lord, I am only, I am sure, echoing the sentiment of everyone here in saying how pleased we all are to see your Lordship once again in that chair.

COMMUNICATION RECEIVED FROM PROFESSOR A. G. GREENHILL, F.R.S.:—

Produce the lines g B and N M in Fig. 6, Plate XXXIV., to meet in C; then C is an important point in ship geometry: it may be called the *instantaneous centre of similitude* of the curves of buoyancy and flotation for constant displacement, as well as of their evolutes. The introduction of this point C simplifies considerably the principles underlying Leclert's Theorem.

For a ship of geometrical form, such as an ellipsoid, the point C is the centre of the ellipsoid; for a cone, C is at the vertex; for a parabolic cylinder or paraboloid, C is at an infinite distance, and the lines g B and N M are parallel to the axis of the parabola.

THE CAUSES OF MYSTERIOUS FRACTURES IN THE STEEL USED BY MARINE ENGINEERS AS REVEALED BY THE MICROSCOPE.

By A. E. Seaton, Esq., Member of Council.

[Read at the Thirty-seventh Session of the Institution of Naval Architects, March 26, 1896; Admiral the Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President, in the Chair.]

I suppose at some time or another every engineer has had personal experience of what are known as mysterious fractures in steel. Their origin and causes have been discussed here and elsewhere, but more often in doing so the question has been begged rather than settled. That there has been an equal number of fractures with wrought iron there is every reason to believe; but owing to its laminated nature the fractures have been small and localised, and seldom of so large and important a character as with steel.

I do not propose to dwell at any length on the instances I am about to give, or of others that have come under my notice from time to time of unexpected and, to a great extent, mysterious fractures in steel plates, steel forgings, and steel castings; but rather to direct the attention of the Members of this Institution to the researches of Professor Arnold, of the Technical School at Sheffield, who, following the theory and line of argument of Dr. Sorby, of Sheffield, has by many years of constant application and unwearying investigation confirmed them, and demonstrated the causes of the peculiar behaviour of alloyed metals when under mechanical treatment, very notable instances of which were given by Mr. Milton in his paper on copper pipes read before this Institution last year.

The particular case to which I would call attention is the sudden and unexpected total fracture of a steel shaft end, which took place in June, 1895, as shown by the drawing Fig. A, Plate XXXVII. The shaft in question was made of Siemens steel by a well-known and old-established firm. It was specified to be of "steel containing from 0·2 to 0·25 per cent. of carbon," and its ultimate tensile strength was to be not more than 30 tons, with an elongation of 25 per cent. in 5 in. This shaft, in company with the other shafts in the ship, was surveyed, tested, and passed, not only by the owners' representative, but also by the Board of Trade surveyor for the district. There was no indication

on the turning of these shafts in the lathe but that the steel was of excellent quality, and, considering that the ship ran continuously from the summer of 1883 until the time of the breakage, there was, judging by the old standards, not much fault to be found; but considering that under close examination a few months before the accident there were no visible cracks or other signs of coming danger, and certainly nothing to indicate such a complete compound fracture as shown by Fig. A, I think you will agree with me that it is, from an engineering point of view, not satisfactory.

A few years ago both owners and all concerned would have been content with the statement that the accident was probably due to fatigue, seeing that the shaft was so many years old, and had run so many thousands of miles; but I am somewhat sceptical of the fatigue theory, for I fail to conceive how any material, such as mild steel—or, shall I say, soft iron?—can by any application of force, which results in a stress far below the elastic limit of the material, produce any internal change in the structure of the material corresponding with what is shown by the diagram; nor, indeed, do I think that any originally sound structure, in which no portion is ever stressed to the elastic limit, can give way by what is known as fatigue. I therefore submitted a section of the shaft to Professor Arnold, the nature of whose researches had just previously come under my notice, and I append hereto his report and opinion on the whole matter, to which I attach more importance than anything I have so far said, or can say:—

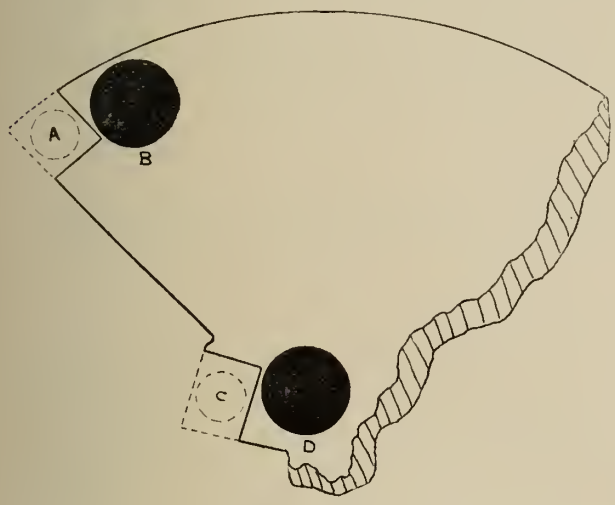

Fig. 1. Half size.

"REPORT ON FRACTURED TAIL-SHAFT OF SS. N.

The transverse half-section received was broken into two quadrants. It was noted on fracture that the core of the shaft was very brittle, and showed irregular grey patches, strongly suggesting that the ingot from which the shaft was forged had "piped." The outer ring of steel surrounding the fragile core seemed fairly tough.

One of the quadrants was examined chemically and microscopically. It is figured half-size in Fig. 1. The black circular holes, B D, indicate the positions from which the drillings were taken for analysis, the centres being $3\frac{1}{2}$ in. apart. The areas, A C, adjacent to the drill holes, show the position from which the micro-sections were machined.

Chemical Analysis.

The figures registered on analysis were as follow:—

Sample B. (Outside of Shaft).		Sample D. (Inside of Shaft).	
Combined carbon	0·310	Combined carbon	0·470
Silicon	0·037	Silicon	0·031
Manganese	0·828	Manganese	0·986
Phosphorus	0·058	Phosphorus	0·167
Sulphur	0·055	Sulphur	0·150

The above analyses show most clearly that the ingot from which the shaft was forged must have been cast very hot, and, for an ingot of the moderate dimensions necessary for the size of the shaft, a very pronounced liquation took place. In round numbers the carbon in the centre of the shaft is 50 per cent. higher than that near the circumference. The manganese has liquated with the carbon to some extent, probably in the form of a double carbide of iron and manganese. The phosphorus and sulphur of the core are each three times greater in quantity than at the circumference. It will be obvious that, even taking the mean analysis, the composition of the original steel was highly unsatisfactory as regards purity, and it was also too hard for the purpose intended.

Micrographic Analysis.

The results obtained in the microscopic examination of the sections are of a most instructive character. It will be well to discuss the microstructures under two heads.

I.—Distribution of the Carbide.

Fig. 2, Plate XXXV., shows a portion of section C, or the hard core of the shaft, magnified about twenty-three diameters. The grey areas, constituting most of the field, consist of iron through which is diffused irregular plates and granules of the double carbide of iron and manganese. A magnification of twenty-three diameters is not sufficient to resolve the irregular laminæ and grains of carbide which will presently be represented in Fig. 3, Plate XXXV. The dark areas of the micrographs will be hereinafter referred to as "steel." The white areas consist of fairly pure "iron."

Remembering that Fig. 2 is a section, it will be obvious on mentally translating it into the solid, that the metal consists essentially of a series of "steel" cells surrounded by irregular and sometimes broken cell walls of "iron," the line of demarcation between the two constituents being very sharp, as will be seen on reference to the next figure.

Fig. 3 (section C) shows a point towards which the angles of three "steel" cells converge. The magnification is about 170 diameters, which, in the present case, is sufficient to reveal the irregular laminations of carbide. A structure of this type is always more or less brittle. The sharp junction lines between two diverse constituents are always liable to rupture under vibratory stresses, because the cohesion or adhesion is inferior to that existing between interlocked constituents. Another cause of brittleness in this material is the fact that the metal is approaching "saturation,"* *i.e.*, "steel" is

* The saturation point of pure iron and carbon steel is at about 0·9 per cent. of carbon. In steels containing 1 per cent. of manganese it is lowered to about 0·65 per cent. of carbon.

the preponderating constituent, which should never be the case in material about to be employed for screw-shafts.

Fig. 4, Plate XXXV., shows the outer shell of the shaft (section A) magnified about 170 diameters. The contrast with Fig. 3 is startling. In the present section it will be seen that "iron" is the "predominant partner," the "steel" crystals being decisively outnumbered; the structure, in fact, consisting of irregular grains of "steel" suspended in a mass of "iron." Notwithstanding this, the structure is not altogether satisfactory, because the junction lines between the "iron and "steel" are very sharp and definite, with little or no intrusive interlocking. This fault is always well marked in unannealed steel castings, and suggests that in the present case too little work was put upon the ingot in forging the shaft.

II.—Distribution of the Sulphide.

Sulphide of iron, even in minute quantity, is readily recognised in steel by the microscope, but it assumes various forms all more or less dangerous to the cohesion of the mass. Its low fusion-point causes it to remain liquid or semi-liquid during or after the solidification of the other constituents; and, under favourable thermal conditions, it is capable of producing the most disastrous effects. The distribution of the sulphide * in the interior of the present shaft assumes three forms which are respectively exemplified in Figs. 5, 6, and 7, Plate XXXV. (All section C.)

(1) In large isolated globules or irregular masses (Fig. 5).

(2) In smaller globules or ovoids forming an irregular train (Fig. 6).

(3) In successive elongated streaks: this form is by far the most dangerous (Fig. 7).

The sulphide generally, but not invariably, occurs in the iron areas, and its adhesion to the adjacent structure is practically *nil*, in fact it is extremely probable that each mass of sulphide is a loose kernel separated by a microscopic fissure from the metal in which it is embedded. Well segregated masses of sulphide, like those in the shaft under consideration, present, after etching, a hard, smooth sectional surface of a dove-grey colour, surrounded often by irregular brown rings. These may be described as rust, formed subsequently to etching, by the acid which has penetrated the surrounding fissures and which is not removed by the desiccating process to which the samples are submitted. These brown rings are therefore unconnected with the structure, but they serve to throw the sulphide into apparent relief. The sections figured are all transverse, and it is more than probable that an examination of a series of longitudinal sections would reveal the fact that some of the rounded sectional areas are the end views of lines of sulphide similar to those reproduced in Fig. 7, and mechanically equivalent to a series of minute cracks in the interior of the shaft.

Summary.

It may be stated that the core of the shaft, dealt with in the foregoing report, suffered from several of the most fatal diseases to which steel is heir, namely:—(1) Bad chemical composition aggravated by liquation. (2) Pipe. (3) Unfavourable structural arrangement of constituents. With reference to the influence of the high phosphorus present, it may be stated that the microscopical

* It must be remembered that the 0·15 per cent. of *sulphur* present is probably equivalent to nearly 1 per cent. of *sulphide*, which is the substance with which the engineer has to reckon.

evidence extant indicates that the phosphide distributes itself like the carbide, but the cohesion between crystals rich in phosphide is very faulty under vibratory shocks.

The centre of the shaft, weakened by pipe, carbon and phosphorus hardness, brittle structure, and riddled with sulphide of iron, is little tougher than good grey pig iron.

It is almost certain that a number of sulphide flaws in the interior gradually worked outwards along the crystalline junctions of the fairly tough metal outside, until under a vibratory shock of unusual force the whole mass ruptured.

The above report is written in ignorance of the circumstances of fracture and of the history of the shaft, and, although such knowledge might modify some of the deductions drawn, still, on the whole, the experimental indications obtained from the sections examined are so decisive, that I think the conclusions arrived at are substantially accurate.

J. O. Arnold."

It will be observed that the amount of carbon present, as shown by analysis, is high, in fact much higher than it should have been; but still it certainly is not high enough to account for fracture, and I believe, yet, that steel with an equal amount of carbon may with advantage be used for shafts. The presence of phosphorus and sulphur is, of course, most objectionable, even in minute quantities; but Professor Arnold has demonstrated to me elsewhere that, sulphur may be present to a considerable extent in a steel casting or forging and be of no serious moment, whereas the same quantity may be present in another form and be conducive to most disastrous destruction of the material. The chemist has hitherto only been able to inform us of the quantity of sulphur present; but as to whether in the dangerous, or non-dangerous form, he is unable to say. In fact he can throw no light whatever on the subject, beyond stating the composition of the material and expressing the opinion that, judging by other specimens he has examined, it is possible, and perhaps probable, that the amount of sulphur indicated by his analysis will render the steel unreliable. It seems to me, therefore, that chemical analysis alone is sufficient, neither for steel, nor for any other compound metal used by the engineer; while, on the other hand, the microscope reveals to us the actual structure of the material, and shows most distinctly whether it is a safe or an unsafe one; it is also capable in the hands of an experienced person of practically determining the chemical analysis—certainly it will determine the chemical analysis very much more usefully than a chemist can determine the mechanical properties of the steel he has analysed; so that it appears that the use of the microscope is likely to be of the utmost advantage to the marine engineer, inasmuch as, with a little experience, aided by illustrations such as I have shown in Figs. 2, 3, and 4, &c., he can see for himself whether the material he is called upon to use is such as is to be trusted; also to the steel manufacturer it will serve an equally good purpose, and one savouring of that of the skilled eye of the steel caster, whose selections of fractured blister steel enabled Sheffield manufacturers in the old

days, as well as to-day, to make with certainty the different qualities of steel required in cutlery, and so established the reputation of that great and growing place, whose progress and enlightenment are so well shown by the splendid means provided by its Technical School for such investigations by Professor Arnold as I have been able to illustrate to you here to-day. I take this opportunity of thanking him for the investigations he has made for me, and for his written report, as well as for the illustrations which he furnished specially for the benefit of this Institution.

The result of Professor Arnold's investigations with this particular shaft tends to show the liability of all steel shafts to begin disintegration from the centre, and the fractures and fissures, when commenced, no doubt gradually spread until they reach the surface. It is true that such fractures may occupy only a portion of the transverse section, instead of being spread over the whole, as shown by Fig. A, Plate XXXVII. Also that, such degradation proceeds without visible indication, and total rupture consequently occurs without warning, and apparently mysteriously. It follows, therefore, that to bore out the centre of a shaft, as is the practice of the Admiralty, which only slightly reduces the nominal strength, really renders it much safer, as it removes that part of the forging which is liable to be of inferior material, and in which disintegration is most likely to commence.

Fig. B, Plate XXXVII., is an instance of the reverse action to that which took place in the shaft shown in Fig. A, which gave way by internal fracture gradually extending to the surface. Fig. B is a photograph of a section of a 10 in. steel shaft which for some time had shown fine hair cracks on the surface near the propeller. When the shaft was replaced the end was broken off to see how far these cracks extended. You will see that they were a considerable distance in from the surface, and there was every indication that the flaws had been gradually spreading, but it took several severe blows to fracture it. It is interesting to note, too, that the angles at fracture are practically uniform in magnitude.

In conclusion, I trust that the discussion which may follow will be of more importance, and possibly of more interest, than the paper.

DISCUSSION.

Mr. J. T. Milton (Member of Council): Sir John Hay and Gentlemen, I think to-day we are under a great obligation to Mr. Seaton and Professor Arnold for bringing this matter before the Institution. This, so far as I know, is the first time in which the question of the microscopic structure of steel or other materials has been brought forward publicly as a means of explaining what would otherwise be called mysterious fractures. There have been several cases where the labours of Professor Arnold and other gentlemen have been utilised to show the microscopic structure of metals

as a means of determining their ultimate composition, but this is, as far as I know, the first time where it has been brought forward to show the cause of some mysterious fractures. I must admit, although you have called on me to speak on this subject, that I know practically nothing about it. I think from this time forth we shall endeavour to study the matter more than we ever have done in the past, and I think it is very probable that microscopical examination will tend to elucidate many matters which have before been mysteries. It is very annoying to engineers who find fractures and and failures take place, to have to admit that all the most careful tests that have been made of the material beforehand have not shown anything wrong with it, and yet when it is put to use it fails from an unknown cause. Many very notable cases of this kind have come before most engineers of experience. There are some points on which I hope Professor Arnold will give us a little explanation. No doubt they are quite clear to him, but it will be interesting to us as engineers to know something more about them. The first point I would mention is some experience that I had, which is mentioned in the first part of the paper, with regard to copper pipes. In Professor Arnold's report, which is given *in extenso*, there is this sentence: "This fault is always well marked in unannealed steel castings, and suggests that in the present case too little work was put upon the ingot in forging the shaft." I would like Professor Arnold to tell us whether the fact of annealing has an influence on the microscopic structure of materials generally. In one of those peculiar cases of copper pipes that I refer to, the copper was perfectly brittle in its unannealed condition, but when annealed it showed the usual amount of ductility. That was a case in which the annealing apparently entirely altered the character of the copper. There are many points that are incidentally treated in the paper that hardly come within the province of the engineer to discuss, but are more in the province of the steel maker—the expert steel maker. The chemical analysis of this shaft appears to me, so far as a non-technical man can say, to be exceedingly bad, and I am very surprised that Mr. Seaton found that the steel gave such a good mechanical test as it did—30 tons tensile strength and an elongation of 25 per cent. Perhaps some steel maker present here, or perhaps Professor Arnold, may be able to throw some light on that point. As an engineer, there is one point on which I do not quite agree with Mr. Seaton; I do not think it is quite in accordance with his own statement here: that is, the question of boring out the centre of the shaft. Mr. Seaton says here, "To bore out the centre of a shaft, as is the practice of the Admiralty, which only slightly reduces the nominal strength, really renders it much safer, as it removes that part of the forging which is liable to be of inferior material, and in which disintegration is most likely to commence." That is perfectly correct, while dealing with such shafts as the one Mr. Seaton has been speaking of, but when you come to the one shown in Fig. B, Plate XXXVII. I think if that shaft had been bored out in the centre it would have broken long before it was put under the hammer, for it would have been bored out at the only part that was good. Although the boring out of a shaft may in some circumstances render it safer, I, as an engineer, would prefer to have the shaft with the core left in it unless considerations of weight were in question.

Mr. J. F. Hall (Member): Sir John Hay and Gentlemen, I am sure we are much indebted to Mr. Seaton for this very valuable paper, and I hope that the discussion on it will bring out some facts which, at present, are not generally known in connection with steel. Mr. Milton has raised a question, and has said that he was "very surprised that Mr. Seaton found the steel gave such a good mechanical test as it did"—30 tons tensile and 25 per cent. elongation; but, as a practical steel maker, I am not at all surprised, because the lower portion of that shaft might very easily stand such a strain, whereas the portion which is fractured would be the top end of the ingot, which we all know

to be the weakest part of the ingot. It is a natural law, in making steel ingots, particularly of large size, that there should be a pipe. All ingots pipe, more or less, and it is perhaps as well that it should be so; but any good steel maker will take care that his ingot is sufficiently long to allow of cutting off that portion which contains the pipe. The pipe, of course, is liquid the longest, and it is only natural that an amount of sulphur, if it is in the steel at all, and the carbon, shall be to a greater extent in the vicinity of the pipe than in the bottom end of the ingot. There is only one law in connection with that, and that is, to make the ingot sufficiently long to cut off all the pipe. In reference to annealing steel, there are many diversities of opinion, but I may say that good steel cannot be spoilt by judicious annealing, whether in the form of a steel casting or a steel forging. Some people think that, having put plenty of work on a steel shaft, there is no need for annealing. I say emphatically, there is quite as much necessity for annealing a steel forging, particularly an intricate one, as there is a steel casting. Now there are certain secrets in connection with steel making that the steel manufacturer is very loath to give to the general public. But there is one which has been mentioned here that I think I should say a few words about. It is in Professor Arnold's report, in which he told Mr. Seaton that it was possible to have a large amount of sulphur in steel without any detrimental effect. That is perfectly true. I have myself made steel castings containing a very large percentage of sulphur, which, as steel castings, as they came from the mould, could be bent very nearly double cold; but, you put that steel casting into an annealing furnace, and you alter the character of it entirely—put it under the hammer, red hot, and it is rotten, and will break like glass, or a carrot; therefore, as Mr. Seaton pointed out in this paper, it is not safe for an engineer to rely entirely upon the chemical analysis of his steel, because that analysis may appear bad; but, at the same time, under various conditions the material gives different results. Of course the paper refers to a shaft made in 1883. That is a long time since; there have been vast improvements made in the manufacture of steel since 1883, and I think that this shaft—and Mr. Seaton, I have no doubt, will agree with me—is an exceptionally bad one. There is no doubt about it—it is bad in all ways. It is a fault that was liable in those days to occur; we did not know as much as we know now about making large steel ingots. It is a comparatively easy method to make small steel ingots, but when you get to making very large steel ingots for these very large shafts, you increase the trouble. A cook who could make a plum pudding weighing 2 lbs. would be bothered very much indeed if he had to make one weighing a ton. I think Mr. Seaton will agree with me that there are now nearly a dozen firms in this country, from whom, if we took, say, 100 shafts promiscuously, made by those respective firms, we should not find one with a composition like the one described in the paper. There is one point in the paper with regard to which I must disagree with Mr. Seaton. Mr. Seaton says he does not believe in the theory of "fatigue." Now it was my privilege some years ago to read a paper before this Institution on the fracture of steel shafts. I treated that paper more from a mechanical point of view than from a steel-making point of view, and we have, in contrast to this particular shaft, shafts constantly breaking, which, when tested, give results totally different from this: very near to the place of fracture they give a very good chemical composition, and perfect tensile strains and elongations. What is the cause of that? It must be "fatigue." Mr. Seaton says that a material of good steel ought not to break under any circumstances. What do you do with a cane, or a piece of holly stick, if you want to break it? You twist it and bend it. The same thing occurs with a shaft. I have mentioned that here before, more than once, but some of my friends criticised me rather severely, and none more so than Mr. Seaton himself. Here we have the fact that really good shafts are constantly breaking, and without this mysterious fracture which is so ably shown by the microscope. I am sure the introduction of microscopical analysis will be of great benefit, not only to the steel

maker, but to the steel user, and I am sure the very best thanks of this Institution should be accorded to Mr. Seaton and Professor Arnold for the very able manner in which they have brought this subject before us, and I hope we have not heard the last of it.

Mr. J. I. Thornycroft, F.R.S. (Vice-President): We are greatly indebted to Mr. Seaton for showing us that the microscope is not only a great power in other spheres, but that, with regard to mixed metals and alloys, it is probably of much greater power than has been supposed. I have noticed in the fracture of gun-metals, to which I think the microscope might be applied with advantage, that when viewed only with the naked eye, you may see that a large portion of the section consists of an oxydised surface, which is not broken at the time of final fracture. The only part of the section which is broken then is quite distinctly different in colour, and I shall take an early opportunity, with the microscope, of seeing whether this may not be applied usefully in examining alloys of gun-metals. I think what Mr. Seaton has said with regard to the distribution of the various elements in the alloys, all of which are called steel, is very important, and the fact that certain constituents may be so arranged, although small in quantity, as to weaken the structure by their particular form, shows that the microscope is really a great power which we ought to take advantage of.

Mr. C. E. Ellis (Associate): Sir John Hay and Gentlemen, as a manufacturer from Sheffield I should like to take this opportunity of concurring with Mr. Seaton in his appreciation of the very good work which Professor Arnold has done at the Technical School at Sheffield, and I can assure this Institution that we in Sheffield are very proud of him, and of the work he has done. A little was said yesterday with regard to the value of the debates in this Institution to naval officers and to naval architects. Now I think Mr. Seaton's paper to-day shows us that there is a third class to whom these discussions are equally valuable. I allude to manufacturers of steel; and on their behalf I thank Mr. Seaton and Professor Arnold for laying before you and us the researches that they have made. My own company have also been making microscopic investigations in very much the same direction as Professor Arnold, and I have here some photographs which I shall be happy to show to any members who may be interested in them, which I think I may say bear out completely the conclusions that Professor Arnold has come to in this matter. I should first like to join Mr. Hall in the remark he made, that this shaft, which, after all, has been continuously running since 1883, has really done very well, and I do not think Mr. Seaton has very much fault to find with it. No doubt the analysis is bad in one particular point, where the fractures commenced, but I should think it extremely probable that those fractures arose from the fact that there must have been excessive liquation in that particular place, so that the fracture would gradually spread to the outside. I have here four micrographs (Plate XXXVII. *a*.), the first three of them being micrographs of fractures where sulphur is present in very large quantities, and the fourth one showing steel in its proper and normal condition as regards analysis and work. The fourth photograph on my sheet is a photograph of the fracture of steel of our ordinary quality, with sulphur as low as 0·2 and phosphorus as low as 0·3, and therefore may be taken as a specimen of excellent steel. It may be interesting to some of the members to compare these micrographs with those of Mr. Seaton's paper. I think, in order to make Mr. Seaton's paper complete, we should have before us a micrograph of steel such as it ought to be, and it is with that view that I tender these micrographs to the Institution, with my best thanks to Mr. Seaton and Professor Arnold for bringing the matter before us.

Mr. G. W. Manuel (Member): My Lord and Gentlemen, I do not come before you, I am

pleased to say, to make mention of my experience in the number of broken shafts, or with regard to such fractures as are mentioned in Mr. Seaton's paper. I am pleased to tell you that since 1881 we have, in the company I serve (the P. and O. Company), used steel shafts and have no thad one fracture, or one broken shaft, or sign of fracture during those fifteen years. Have the shipowners' inspectors, after all this record, to go about with the microscope and find out the suitability, or not, of steel shafts to be used in their companies' vessels? Those flaws which have been represented in Mr. Seaton's paper are not found in my experience. It is not new to me, I may say, the testing by the microscope. I have, along with Mr. Ellis, had similar experience of that in 1892. A screw-shaft, the material of which was under survey—one of four shafts—not only by Lloyd's, but by the Board of Trade, passed all examinations and tests; while, under a suitable and certain test usually applied by me, the material failed most seriously—so much so that the makers condemned the shaft before it was put on board, and were quite satisfied, without using a microscope, that there was something wrong with the steel. I believe at the time the cause was not quite clear; however, they went into the matter very minutely, and, amongst other methods, used the microscope, which clearly showed them, by taking like small samples of metal from the broken samples of three others which stood the test, why this one failed under my test and was condemned. It was fortunate this test was applied, otherwise, having passed both the Board of Trade and Lloyd's, it would have gone to sea and, in all probability, we should have had fractures such as we see here, or a broken shaft to record. I should like to know a little more about this shaft of Mr. Seaton's. What is the percentage above the usual Board of Trade rules, and in what position of the ship was this shaft placed? Was it in the stern or in the tunnel, or was it a crank shaft?

Mr. Seaton: It was a tunnel shaft in a twin-screw boat, and close to the coupling, next to what we call the tube shaft.

Mr. Manuel: I wished to ask that, because shafts vary in fatigue according to the position they occupy. Twin-screws are overhung, and are subjected to a great deal of vibration at the stern, which is not the case in other parts. No doubt, from the analysis of the atoms taken from this shaft, which we have had before us, it appears to have been made of faulty material—at these parts. I am not here as a chemist, but I may have to be a "microscopical" surveyor, in accordance with remarks in this paper. It will be a new thing for me to go about taking a microscope, and having small pieces cut out of shaft centre and bolt holes, and testing the steel in the manner which is represented here, after a shaft is finished. I feel not at all alarmed, and quite satisfied that good steel shafts, at present in use, or to be used, when made by the best makers, and properly tested, are thoroughly reliable. We have heard a great deal about twin screws, and the necessity for twin screws, because the shaft in a single screw may fail. I have not that fear. In 1881 the company I serve commenced with the first of 110 steel shafts made by the best makers, and I have not the least fear of those shafts. I think if steel shafts are carefully made and tested, that no fear need be entertained by the passengers, and the travelling public, in a single screw steamer. One steel shaft, in particular, has run nearly one million miles with no signs of flaws. I quite agree with Mr. Seaton in his remarks about fatigue: if a shaft of good material, properly designed, is not fatigued beyond what it can stand, whatever position it is in, in the vessel, continuous work has nothing to do with it, unless, by lightness or other means, the shaft is reduced in size. With regard to cutting out the centre of the shaft, or *hollowing* the shaft, I disagree with that entirely, because, in iron and steel, all the fractures that I have seen commence from the outside, unless in the old iron shaft days, when they could not weld a shaft together, because they had not the powerful hammers, and the blooms and bars were

not welded in the centre of the shaft. I have seen one iron shaft give way from the fact that it was not solid in the middle, but hollow, not welded together at the centre, it gave way from the centre outwards. Generally our marine engineers and surveyors, when they find marks outside the shaft, bore a hole in it, and if it does not extend beyond the Board of Trade's and Lloyd's rules, the shaft may work for years, being solid in and towards the centre. It is invariably our experience that shafts do not break from the middle, they break first from the outside, more especially nowadays. I have two tests made from all steel and iron shafts each end, $1\frac{1}{4}$ in. square bar, 13 in. long. It is put between two supports, and a weight of 10 cwt. dropped on the top of it, to see how many blows that bar will stand, a certain number being specified; the bar is reversed after every blow. They begin to fracture on the outside in good steel after seventy and eighty, and sometimes ninety blows. I take notes when the fracture commences to take place, and that fracture will go into the test piece one-third of its depth, so much from each side, and after that it will stand fifteen blows before it finally breaks; showing that, while the outside has gone, the centre part is holding on; and, had that represented a shaft in a vessel having an inside flaw, the shaft would have continued to hold on, and carried the ship into port, whereas in a hollow shaft it would have failed. I really do not think that boring out the shaft adds to its strength. I should like to say a word about those microscopic diagrams, and to ask what is the area of those figures, represented here, showing the sections under the microscope. It is represented here as magnified 170 diameters from the original, that is, less than $\frac{1}{16}$th.

Mr. Seaton: The diameter of the actual piece will be 170 times less than that of the figure there.

Mr. Manuel: If I were a surveyor and a shaft passed the Board of Trade and Lloyd's rules, would I be justified in condemning that shaft on such a small and infinitesimal piece? Because that is what the microscopic test in accordance with Professor Arnold's ideas impiles. I do not think it is necessary to give up the present practical tests used by the Board of Trade and Lloyd's, but I should like to increase their value, for this reason, that this fine steel I use is 60 per cent. stronger than best iron; therefore I think a material that has 60 per cent. more strength than that of iron in a shaft should be put to a more crucial test. I believe the ordinary tests now made on steel for steel shafts are not sufficient to define between the *best* steel and *inferior* steel, unfit for shafts. Gentlemen, I will not detain you any longer. I feel that this is a matter of great importance to both the Mercantile Marine and Her Majesty's Navy. Unless you have a good shaft it may lead to very lamentable occurrences, even in a twin-screw battleship in time of action. I have to thank Mr. Seaton for bringing this paper forward, but I feel inclined to think it is a matter more to do with the steel manufacturer of shafts in the molten state than with the marine engineer, and I hope the time will never come when we shall have to carry a microscope about for the purpose of examining a shaft in order to determine its fitness for use on board any vessel.

Mr. J. F. Hall (Member): May I be allowed to make an explanation on a matter with regard to which I may have been misunderstood. It is as to what Mr. Manuel said with reference to what Mr. Seaton calls the "fatigue" of the shafts. What I meant by "fatigue" was not the ordinary fatigue in a shaft working *in line*, but I wished to refer to the undue fatigue laid upon a shaft when working *out of line*, and working in a way it ought not to do: for instance, in the ordinary warping and straining of a long ship in a heavy sea.

Mr. Archibald Denny (Member of Council): The point I wish to refer to, also, is the question of fatigue. If I understand fatigue in the same sense as Mr. Seaton understands it, then I differ from

him. I think there is such a thing as fatigue; and, evidently, how long a shaft will stand is very much influenced by the structure of the material and the homogeneity of it, as shown by those diagrams. With regard to the remarks made by Mr. Manuel, I am sure we are all pleased that he has had such immunity from accident, and it shows the great care he personally has taken in making everything amply strong, even stronger perhaps than constructors may have thought necessary, and even stronger than the standards set up by Lloyd's and the Board of Trade. I am delighted to find that this paper of Mr. Seaton's has not started a scare. Very often we see in this Institution, when something new is brought forward, a scare starts up. I am quite sure that Mr. Seaton did not intend that, and I am glad to see there is none. We know that, for some considerable time, anything mysterious that happens in the human body is put down to the presence of microbes; now we are evidently about to find that all the mysteries in the behaviour of steel are due to microscopic flaws. I think the microscopist and chemist, in this case, very much resemble the surgeon and the doctor. The doctor, we are told, is the man who pours medicine, of which he knows little, into bodies of which he knows nothing at all; whereas the surgeon we all admire—he is dealing with an exact science, and is successful. But we could not do without the doctor, and we cannot do without the chemist in steel for analysis, and I am glad to think that we are to have something equivalent to the surgeon's work in this microscopic analysis. I disagree with Mr. Milton and Mr. Manuel as to the value of the central hole in shafts. My opinion is that it is a most valuable thing. At any rate, if it is a matter of dispute whether the outside or the inside of the shaft is of most value under fatigue, and for the lasting of the shaft, if you put a hole through a steel shaft you certainly see that there are no serious flaws in the centre of it where they are most likely to be, and the reduction in strength is very small indeed; moreover, if you wish to make it up again you can easily put a little on the outside. I would like to see hollow shafts adopted universally, and I think it would be a good thing if all owners would consent to have this done; but hard times, I suppose, make difficulties for owners, and they are not prepared to do so. What Mr. Manuel said as to his method of testing, as I understood it, by percussion is admirable. I wish to thank Mr. Seaton and Professor Arnold for this paper.

Mr. R. Matthews (Visitor): My Lord and Gentlemen, as a visitor attending your interesting meetings, the possibility of being asked to say a few words on the subject of this paper never occurred to me, but, being connected with Sir Joseph Whitworth & Co., Limited—the largest makers of shafting—I feel in duty bound to do so; but, before proceeding further, wish to express my pleasure and thanks to Mr. Seaton and Professor Arnold for the interesting paper, and hope that the old proverb may be fulfilled, that "there is no ill but good comes of it." In my business experience it has fallen to my lot to be called in to replace broken shafts, and, on inquiry, I have found some actually made from ingots cast from the remains of a melting for steel casting. Possibly the one under discussion was such; the phosphorus and sulphur are too high: had it been made from Swedish iron these constituents could not have been so high, and it is so irregular it must have been well looked after whilst working to have survived so long. The subject is so important that it is worth the attention of some of our politicians to try and devise a means of giving some consideration for good material and workmanship, and of putting an end to the auctioneering business which has taken possession of our Government. I think it is the usual practice of all respectable firms to use microscopes for the examination of fractures, but not to rely on them alone, as it principally shows the arranging of the fibre (or rather the effect of the forging, or physical treatment), therefore we could not safely do so; in fact, we must adhere to both the chemical and physical tests; but in the latter we might, with advantage, give up the ultimate breaking strength and rely on the elastic limit and elongation—especially now that the

maximum power with the minimum weight is required in all our Admiralty work. Mr. Seaton's remark, that the shaft whilst being broken did not give way at the flaw, but at a sound place, leads me to remark that, for steel forgings, the days of the steam hammer are numbered. The proper way to make a shaft of that nature—in fact, any steel forging—is by the hydraulic press, as it gives the metal time to flow, whereas the steam hammer gives a number of severe shocks (which is very bad for the material), and unless proper attention be given to the forging under the hammer, and the operation most skilfully carried out, it is possible to produce very faulty forgings. It is common knowledge that a shaft can be so forged under the hammer as to be quite hollow in the centre. The proper way to make a shaft of this nature is by the hydraulic press, which treats the material gently, and gives it time to assume its natural state of rest; and not to take an ingot about the size of the collar—allowing no forging to be done to the collar—and then neck it down under a hammer, weakening it for life; but to do as Sir Joseph Whitworth & Co., Limited, do, *i.e.*, to forge the ingot down to a diameter less than the collar, permitting sufficient forging to be put into it, then gently reduce it to the diameter of the shaft, and afterwards put it into a collaring press and jump up gradually the collar, so getting the metal to flow and become fibrous from the body of the shaft round into the collar, thus getting the maximum strength without punishing the metal. Another very important process is: after forging, to anneal, and, in crank-shafts, to re-anneal, after it is rough machined as near the finished sizes as possible. With reference to what had been said about fatigue, it is my opinion, based on experience, that every shaft has a "life," and physically resembles a human being whose life depends (1) on a constitution, or constituents; (2) on its treatment during development; (3) on the way it is worked afterwards. Consequently, if you want a good shaft, you must use good materials, such as would give you homogeneous steel with much less phosphorus and sulphur than the sample under review; but to use, say, Swedish iron at £6 10s. per ton, instead of hematite at about £3 per ton, means a difference in the cost, and, for the additional treatment and annealing, consideration in price ought to be given; therefore, those pioneers who are wanting so much power out of little weight, must be prepared to "pay the piper," as long life could not be expected from poor material. The secret of Mr. Manuel's success has been his insisting on a more severe test than the ordinary, thereby compelling the use of Swedish iron. We have had much better results by using a stronger steel, giving a higher elastic limit than the usual tests, and it is being very largely adopted for torpedo-boat destroyers, and other purposes.

Professor Arnold (Visitor): My Lord and Gentlemen, in the first place, I should like to express my thanks to my friend Mr. Seaton for his kindness in enabling me to bring this matter of the micrographic analysis of steel before the members of this Institution. Before I go further I should also like to deal with a point raised by Mr. Manuel, because I fear, from his remarks, that my report has not been at all as clear as it should be. Mr. Manuel spoke of going about inspecting steel shafts with a microscope in his pocket. That is not at all the manner in which the microscopic analysis of steel is carried out. He would also have to carry a very large illuminating apparatus in his pocket. I am afraid the fault is mine. Steel to be examined by the microscope first requires very carefully sectioning, then very delicately polishing to get a dry unforced polish, and it then requires etching. A rough idea of what etching really means may be given in simile. You may have all noticed that after a heavy flush of rain the structure of a macadam road is shown up very well—gritstone and granite lying alongside each other: it is very similar to the steel prepared for micrographic analysis. Mr. Manuel I understood was referring to a pocket microscope for examining the fracture of steel. The fracture of steel is in no way, or hardly in any way, connected with its micrographic constituents.

I should like to make that clear at the outset. Mr. Milton has raised a point as to whether a steel casting could be distinguished by the microscope before and after annealing. Fortunately Mr. Seaton has in his possession (see Plate XXXVI.) an example which shows in a most excellent manner (and it was made independently of my work altogether) the profound structural changes resulting from the process of annealing, the action of which is to some extent equivalent to properly forging or properly pressing steel. There is a great analogy between the two processes. Now it is very difficult without the actual samples here to describe them; but an unannealed steel casting almost invariably consists of two constituents, one of which, for the purpose of simplicity, I have called "steel," and the other "iron." They are lying alongside each other, and they form very peculiar patterns, but in the unannealed steel casting the line of demarcation between the iron and steel casting is most remarkable. After annealing you get intermixture and interlocking, which accounts in a large measure for the increase in the ductility of the steel casting. Mr. Milton referred to the question of some copper experiments. Perhaps some members of the Institution may have observed that, in conjunction with one of my demonstrators, I published in *Engineering* some sections of copper containing small quantities of impurities, and that showed clearly how a very minute quantity of impurity might ruin the properties of copper. I do not know whether Mr. Milton referred to pure copper or ordinary copper.

Mr. J. T. Milton: It was commercial copper, not pure copper, and, although it was exceedingly brittle, annealing restored it perfectly. I do not think that was quite parallel to the case you published in *Engineering*. There, I take it, the structure was bad, and there was a defect in it, but annealing restored this copper perfectly.

Professor Arnold: In a case such as Mr. Milton refers to we have to go rather into technical matters. Of course, the ultimate portions of matter are molecules, and, as we know, in the past the properties of metals have been referred to the cohesion between these molecules. I do not think many people can possibly grasp what a molecule is. Lord Kelvin's definition has arrived at it as nearly as can be. He calculated that if you magnified a single drop of water up to the size of the earth, the constituent molecules would be as big as a boy's marble, so that I do not think we can refer many metallurgical effects to molecules. We have crystals or grains, consisting of groups of molecules, but we must recognise that the inter-molecular cohesion is quite distinct from the inter-crystalline cohesion; and I think it is the inter-crystalline cohesion which determines the mechanical strength of metals, which is the matter of importance for engineers. It is quite possible for the inter-crystalline cohesion between a series of crystals to be faulty. I have observed that in the case of steel castings, and yet more in annealing, the joints, as it were, weld up, and you have a great increase in toughness, and to that I should attribute Mr. Milton's increase of toughness in his samples of copper. Mr. Denny and other gentlemen who have spoken have raised a very interesting point with reference to fatigue. The question I have often tried to get at is, what is fatigue? To say a shaft is tired and breaks is not likely to lead us to any facts guiding us as to what fatigue is. I take it that if the term fatigue means a gradual loosening between the joints of crystals it is very probable fatigue does exist, but it is a very bad name for it.

Mr. Archibald Denny: I mentioned that it was very difficult to define exactly what it was, but that was a very good definition, I thought.

Professor Arnold: I will not detain the meeting much longer. Mr. Matthews spoke of homogeneous steel. As far as I know, no such material exists; certainly the material used for screw shafts,

examined microscopically, is far from homogeneous. It is a mixture of utterly distinct crystals of iron and crystals of steel lying alongside each other, and it is only when examined under the microscope that one grasps that steel is a compound structure. Even "steel" crystals themselves are compound, so that, I think, homogeneity is almost impossible. As far as I know, there is only one special steel in a special condition that can be truly called homogeneous, and that is iron with carbon 0·91 per cent., which Mr. Matthews, I feel sure, will not for a moment advocate for screw shafts. In conclusion, I should like to express my thanks to Mr. Ellis for the kind references he has made to my work, and also for supplementing the micrographs which I presented with the report, by the admirable micrographs of his own, one of which, it must be admitted, presents the structure characteristic of an ideally tough steel.

Mr. C. E. Ellis: Before Mr. Seaton replies I should like to add, to prevent any misapprehension, that the micrographs shown by me were taken from specimens prepared in the same manner as Professor Arnold has described, that is to say, carefully polished and then treated with acid.

Mr. A. E. Seaton (Member of Council): My Lord and Gentlemen, Mr. Milton raised an interesting issue when speaking of the testing of material. It is quite true that this shaft passed successfully the Board of Trade mechanical tests, and I have no doubt that the same shaft would do it to-day, because, probably, the test-pieces were taken from the other end of it; that is wherein I disagree with the Board of Trade and Lloyd's tests altogether—especially the Board of Trade tests. They never test the steel that goes into the ship, but that which does not go into it. I think the great beauty of Professor Arnold's method is that although it does not test the actual material that goes into the ship you can test your shafts as you do your cheese when buying: bore a little hole and test the core, so to speak, with the eye. There is nothing to prevent anybody from boring in the end of the shaft or from the coupling. Or you might take the core from a bolt-hole. You would examine this core, which is actually a piece of the shaft that goes into the ship, whereas the fag end that is forged out so nicely by some makers, and tested to the satisfaction of the Board of Trade and other surveyors, is not really a portion at all. The question of fatigue has come up, but I will not deal with it to-day. I have my own views on that, but it is rather foreign to the present subject. Mr. Thornycroft has raised an important question, and that is, how far the microscope can be used in dealing with gun-metal? I am more interested in the manganese bronzes, because they display, even more than gun-metal, the peculiar fracture he has spoken of. We cannot expect Professor Arnold to do this, because he is in a steel district, among people interested solely in steel; but some one else who has the leisure and the means might very well follow up this investigation, because, I think, there is a very great future for the bronzes. I myself have used them very extensively in the construction of torpedo-boat destroyers, and with such advantage that the structure composed of manganese bronze castings has been lighter than the well-known light structures of forged steel bars usually seen in these boats. As to Mr. Manuel's remarks, well, you know, Mr. Manuel need not worry himself about the microscope. I do not think he will ever be called upon to go about with one in his pocket, for his shafts are never stressed in a way requiring this. I am afraid, if we attempted to construct torpedo-boats or fast cruisers under the rules that Mr. Manuel follows, that we should not attain the high speeds we do. I know with the very large factors of safety he is accustomed to in his own practice there is not much chance of a shaft breaking. No wonder he can say that of the hundred steel shafts he has had there have been no breakages; probably if some of them were of cast iron they would not have broken. I am not laughing at Mr. Manuel. I merely say that that really is the case with such shafts as he uses. There is not one part of them stressed to anything like the extent we are accustomed to; in fact, there could be no progress if we followed

out Mr. Manuel's practice. I believe in his service not only are the stresses very low, but the speeds at which his engines are run are very low. Mr. Ellis having kindly presented to the Institution, for publication in the Transactions, a photo-micrograph of a specimen of really good tough mild steel, suitable for propeller shafting (Fig. 4, Plate XXXVII.*a*.), the members will now have a standard to judge by. I do not think I have raised a scare to-day, as suggested by Mr. Denny. On the contrary, I think the tendency of what has been said by the speakers would be to allay a scare, because I have shown that for thirteen years an abominably bad shaft ran successfully, and when it gave way in the end it fortunately did no harm. The shaft in question was at the end of the tunnel, and next to the tube shaft; possibly the final wrench was caused by a little racing. I think myself to-day we have given steel a good character rather than a bad one, because if the imperfect, and I may say wretched, steel of which this shaft end was composed could work for thirteen years, then with the sound good steel of which Mr. Manuel has spoken we should go on for ever, as his shafts apparently do. It would be a bad thing for steel makers, however, if shafts were to go on for ever, but that is what they are all trying to accomplish. Mr. Matthews spoke of the hammering. There is a story told of a fox that lost his tail and thereafter tried to persuade all other foxes that a tail was an encumbrance, and that they would do much better without it. Of course we know how Whitworths lost their steam hammer and got their press; having got it, I admit they have demonstrated to steel makers that the press is undoubtedly the best and most reliable instrument for dealing with large steel forgings, but I would point out to Mr. Matthews that many steel makers, especially those who have the handling of steel for small forgings, maintain, and with a considerable amount of truth and some foundation, that the steam hammer is better than the press; but these are trade matters which we should not go into here. Whether hematite is bad stuff to make shafts of I will not deal with. I am only surprised to hear the statement. I may mention for Mr. Matthews' benefit that the firm who made the shaft in question professed at that time to use only Swedish iron. I do not know whether they did or not; it certainly does not look like it. Gentlemen, I thank you very much for giving me so patient a hearing.

The President (the Right Hon. the Earl of Hopetoun, G.C.M.G.): Gentlemen, I feel certain it is your wish that the thanks of this Meeting be tendered to Mr. Seaton for the admirable and interesting paper which he has read.

MEASUREMENT OF FEED AND CIRCULATING WATER, ETC., BY CHEMICAL MEANS.

By C. E. Stromeyer, Esq., Member.

[Read at the Spring Meetings of the Thirty-seventh Session of the Institution of Naval Architects, March 26, 1896; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

It is well known that the quantity of air which enters a furnace, or of the gases which pass up the funnel, cannot be accurately measured by any mechanical means, and in all modern boiler trials, where it is desired to estimate the true weight of the waste gases, recourse is had to chemical determinations. A careful analysis is made of the carbon contained in the coal, and of the carbon (in the form of carbonic acid) contained in the waste gases, then by multiplying this ratio into the weight of coal burnt per hour, the weight of the waste products is obtained. This weight is then multiplied into the specific heat, and into the difference of temperature of the air which enters the furnace, and that of the gases which pass up the funnel; and the product is the heat carried away. Complicated as this method may appear, it gives results which are far more accurate than any that can be obtained by direct measurements with an anemometer, and it therefore occurred to me, that a similar process, if simplified, might with advantage be applied to the measurement of streams of water not only on land, but also at sea. As will be seen by the experiments detailed in this paper, I have succeeded in measuring both the amount of steam condensed and the circulating water of a marine engine, a task which does not appear to have been previously attempted; the results, too, are sufficiently accurate to compare well with those obtained under more favourable conditions on land engines, in which cases the measurements have always been made by positive and mechanical means.

An inquiry amongst my chemical friends elicited the fact that there are many simple tests for chemical substances, which might be depended upon for estimating them to within one-millionth of the weight of water in which they may be dissolved. The nitrate of silver test for salt (sodium chloride) is one of these, and it was therefore decided to try by this method a preliminary experiment on the feed water of a marine engine. A measured quantity of salt (sea) water was slowly injected into the condenser of the engine while at work, and subsequently a chemical analysis for salt was carried

out, both on a sample of sea water and on a sample of this adulterated feed. Supposing that their salinities stood in the ratio of 100 to 1, and supposing that the rate of injection of the sea water was half a gallon per minute, then evidently 495 lbs. of steam had been condensed during the same period, with which the injected sea water had been diluted down to a 1 per cent. solution. 49½ gallons per minute would therefore be the volume of condensed steam.

Measurement of Feed Supply to Land Boilers.

The value of such a method of measuring quantities of water will, of course, depend upon the accuracy attainable, not only as regards the chemical tests, but also as regards the whole process. Being unable to compare the results of this method as applied to the feed water of a marine engine with the readings of a feed meter, an experiment was carried out ashore, in which this could be done. It is well known that all town waters contain small quantities of salt in solution; in order, therefore, to find the quantity of water which has been fed into a land boiler, it was only necessary to take daily samples, both of the feed water (town water) and of the boiler water, and to ascertain the relative daily increase of weight of salt in the boiler. Now although the Glasgow supply, which is considered to be one of the purest drinking waters, contains only between one and two grains of salt per gallon, or about one five-hundredth per cent. by weight, yet the nitrate of silver test is so accurate that it can be depended upon to determine the exact amount to within one per cent. In carrying out this experiment I was at first seriously inconvenienced by irregular results, but found that these were due to condensed water in the water-gauge pipe from which the samples had been drawn. In subsequent experiments a cock was fitted direct to the boiler shell, and from that day the readings were regular.

The results are contained in Table I. The meter readings were commenced on Monday about noon, and ended on Saturday at about the same time. The town water was constantly running into a large tank holding about 5,000 gallons, from which a sample was daily taken for analysis. The feed was drawn from this tank and pumped into two externally fired boilers, of which the smaller one was worked 9¾ hours per day while the large one was worked irregularly, sometimes throughout the night. The respective working hours during the five days of the trial were 48½ and 78¼ hours. Of course, these boilers were under steam for nearly the whole period of 119¼ hours. Another set of samples of water was daily taken from each boiler and analysed. On these occasions the height of water in the gauge glass was noted, as well as the steam pressure, for the salinity of the boiler water had to be corrected on account of the evaporation which would take place during the time that it was being blown into a

bucket for sampling. Thus the heat contained in the water while in the boiler would be proportional to its temperature, say 322° Fahr. Immediately after leaving the boiler its temperature would be lowered to 212° Fahr. and the heat thus liberated would evaporate a certain amount of water, which ought, of course, to be returned to the samples when cold. It amounted to about 15 per cent. The readings of the water-level were necessary in order to be able to estimate the volume of water in the boiler, which had also to be corrected on account of the difference of expansion of the boiler and the water within it. Both corrections have been carried out in the table, and amount roughly to 20 per cent.

TABLE I.

Chemical Estimate of Town Water Feed Supplied to a Pair of Land Boilers.

Day of Week. (Noon).	Main Boiler.			Auxiliary Boiler.			Weight of Salt in both Boilers.	Daily Increase of Salt.	Saltness of Feed Water.	Estimated Daily Volume of Feed Water.	Working Hours.	
	Corrected Water Volume.	Corrected Saltness of Boiler Water.	Weight of Salt in Boiler.	Corrected Water Volume.	Corrected Saltness of Boiler Water.	Weight of Salt in Boiler.					Main Boiler.	Auxiliary Boiler.
	Cub. Ft.	Grains per Gallon.	Grains.	Cub. Ft.	Grains per Gallon.	Grains.	Grains.	Grains.	Grains per Gall.	Gallons.	Hours.	Hours.
Monday ..	266·2	3·40	5,640	150·4	5·54	5,190	10,830	—	—	—	—	—
Tuesday ..	269·3	9·18	15,410	142·3	8·51	7,550	22,960	12,130	1·32	9,190	21¾	9¾
Wednesday ..	264·4	12·05	19,860	139·5	11·84	10,300	30,160	7,200	1·29	5,580	12¾	9¾
Thursday ..	264·8	15·79	26,070	140·5	14·73	12,900	38,970	8,810	1·46	6,040	12¾	9¾
Friday ..	268·8	17·82	29,860	146·2	17·77	16,200	46,060	7,090	1·24	5,720	9¾	9¾
Saturday ..	268·6	22·75	38,100	144·9	20·83	18,820	56,920	10,860	1·22	8,900	21¼	9¼
Totals ..	—	80·99	—	—	79·22	—	—	46,000	6·53	35,430	78¼	48¼
Means ..	—	16·20	—	—	15·85	—	—	—	1·31	7,086	—	—

It will be seen that the absolute weight of salt in both boilers could be estimated from the chemical test. It slowly increased from 10,830 grains (= 1½ lbs.) to 56,920 grains (= 8⅛ lbs.), or from ·006 per cent. to ·032 per cent. As the average saltness of the town water was 1·31 grains per gallon, it required 35,430 gallons to supply the 6⅝ lbs. (or exactly 46,000 grains) of salt, and that is the estimated volume of the feed. During this period of 119¼ hours the water meter recorded 37,270 gallons. The difference, exactly 1,840 gallons, may be due either to an error of 5 per cent in the chemical determination of the feed, equal to one-fifteenth of a grain per gallon (which will be discussed later on), or it may be due to a slight leakage of 30 gallons per day, say 1¼ gallon per hour, which is only ·4 per cent. of the feed supply. It must be remembered that the average saltness of the boiler water is 16 grains per gallon, while the feed

only contains 1·31 grains, and a leakage of 150 gallons in five days would carry away 2,420 grains of salt, which is as much as would be supplied by the above-mentioned 1,840 gallons of missing feed water.

A method which will, under such exceedingly difficult conditions, give a result that is correct to within ·4 per cent., is surely worthy of a more general application. I would, however, wish to point out that, although in this case all the readings and the samples were taken by the boiler attendant, so that it would seem as if this method could be easily applied to land boilers, yet, as there are certain precautions which must be taken to ensure the desired accuracy, I would not recommend it for general use. These precautions are, that the boilers should be filled with fresh water before starting, otherwise the loss of salt due to even small leakages will be excessive; leakages should, if possible, be stopped entirely; and, unless the samples and water-gauge readings are only taken on two succeeding Sundays, when there is no steam in the boiler, it will be necessary to make careful allowances for the boiler temperatures, the corrections amounting to about 20 per cent. for a working pressure of 80 lbs. per square inch.

Measurement of Feed by Salt Brine Injections.

The above experiments were, as already mentioned, undertaken for the purpose of checking the results of some trials at sea, which, it had been vainly hoped, would contain sufficient internal evidence either to confirm or condemn the method. It was believed that the steam weights, as estimated from the indicator cards, would be found to stand in some definite relation to the feed water; but that no dependence can be placed on them will be evident from a glance at Mr. D. Croll's paper (Transactions of

TABLE II.

Proceedings Mechanical Engineers Year and Page.	Vessel.	Feed-water per hour. 1892, p. 160-1.	High-Pressure Cylinder after cut-off.	Mean-Pressure Cylinder at 0·6 stroke.	Low-Pressure Cylinder before release.
		Lbs.	Per cent.	Per cent.	Per cent.
1890, p. 211	*Fusi Yama*	7,860	16·9	—	29·2
1890, p. 223	*Colchester*	43,020	28·0	—	47·3
1890, p. 235	*Tartar**	21,564	54·8	50·9	39·7
1891, p. 215	*Iona**	8,616	36·6	25·1	40·9
1892, p. 155	*Ville de Douvres*	66,180	19·4	—	27·5

* Note.—The jacket water is included.

the Institution of Naval Architects, 1894, Vol. XXXV. page 425), in which, out of seven engine trials, the indicator cards only accounted for from 90 to 67 per cent. of the total steam. In the full power trials of the Research Committee on Marine Engines Trials, which lasted many hours, the variations are even greater, as will be seen from Table II., and in the exhaustive trials which were made by Professor Osborne Reynolds, F.R.S. (Proceedings Inst. Civil Engineers, Vol. XCIX. p. 194), similar results are obtained. See Table III.

TABLE III.

Moisture in Steam. Estimated from Indicator Cards at Mid Stroke. Experimental Engine, Owens College, Manchester.

High-Pressure Cylinder.		Mean-Pressure Cylinder.		Low-Pressure Cylinder.	
Revolution.	Moisture.	Revolution.	Moisture.	Revolution.	Moisture.
146	39 per cent.	127	34·5 per cent.	109	48 per cent.
229	27 ,, ,,	215	34 ,, ,,	184	47 ,, ,,
322	21 ,, ,,	320	27 ,, ,,	276	36 ,, ,,

It is also a matter of everyday experience, that the steam weights estimated from indicator-cards of different cylinders of the same engine rarely agree, and nobody should be surprised to find that the feed-water measurements obtained by me during these very short trials, differ from the indicator-card readings. The results of the experiments which are detailed in Tables IV. and V., Engines A and B, cannot therefore be looked upon as proving the accuracy of the method, but have been included here as an illustration of the simplicity of its working; and even if these estimates are not accepted as being absolutely correct, they are certainly of relative value, being made under identical conditions, and they therefore throw some light on the question of economy of working when the engines are linked up or when the steam is throttled. In experiment No. 1, Table IV., the salinity of the feed water is perhaps too low, the injection having been started only five minutes before sampling, and the estimated volume of condensed steam and the moisture in the cylinders would be too high. In both these engines much trouble was experienced with the high-pressure indicator, and in experiment No. 1 there is some doubt as to whether the number of revolutions should not have been 88 instead of 80.

The method of carrying out these experiments was as follows. (Fig. 1, Plate XXXVIII). A small indiarubber hose was connected to a sea cock X, and supplied sea water to the graduated glass jar J; a pipe p, capable of withstanding an internal vacuum, was led from the bottom of the jar J to a special cock A under the air pump

TABLE IV.

Engines A, 18 in. and 36 in. Diameter, 24 in. Stroke.

Reference number	1	2	3	4
Conditions under which the engines were worked	Linked up.	Throttled.	Throttled.	Throttled.
Time of commencing to inject sea water into the air pump	12.21 p.m.	12.21 p.m.	12.21 p.m.	12.21 p.m.
,, ,, collecting samples of water and taking indicator cards	12.26 p.m.	12.34 p.m.	12.41 p.m.	12.49 p.m.
Steam pressure ... lbs. per sq. in.	102	98	100	110
Receiver pressure ... ,, ,,	2	2	2	1
Vacuum ... inches	27¼	26½	26	26¼
Revolutions per minute	80	84	98	73
Indicated horse-power	Spoilt.	152	237	99
Steam weights, estimated from high-pressure indicator cards ... lbs. per hour	—	2,575	4,110	2,220
,, ,, ,, ,, low ,, ,, ,, ... ,, ,,	2,336	3,217	4,622	2,198
Chemical Determinations.				
Salinity of feed-water samples (see Table XI.) ... grains per gallon	63·3	70·2	72·9	87·9
,, ,, sea ,, ,, (see Table XI.) ... ,, ,,	1,963	1,974	1,960	1,980
Measured volume of sea water injected into air pump (see Table VI.) ... gallons per hour	12·68	12·62	19·72	11·70
Estimated volume of condensed steam ... ,, ,,	380·5	342·5	510·47	251·6
,, weight of condensed steam per indicated horse-power ... lbs. per hour	Spoilt.	22·5	21·5	25·4
,, moisture in high-pressure cylinder ... per cent.	—	24·9	19·5	11·8
,, ,, ,, low ,, ,, ... ,,	38·6	6·2	9·5	12·3

The indicator cards of these trials are not satisfactory.

TABLE V.

Engines B, 15 in., 25½ in., and 41 in. Diameter, 27 in. Stroke.

Reference number		5	6	7	8	9
Conditions under which the engines were worked		Throttled.	Linked up.	Full speed.	Full speed.	Full speed.
Time of commencing to inject sea water into the air pump		9.26 a.m.	9.43 a.m.	1.16 p.m.	1.48 p.m.	4.19 p.m.
,, ,, collecting samples of water and taking indicator cards		9.36 a.m.	9.53 a.m.	1.26 p.m.	1.58 p.m.	4.29 p.m.
Steam pressure	lbs. per sq. in.	142 to 116	120	159 to 142	160	150
No. 1 receiver pressure	,,	1	24½	49½	51	45
No. 2 ,, ,,	,, ,,	—7½	—4	4½	4½	4¾
Vacuum	inches	24	26	25	22	24½
Revolutions per minute		46	56	102	101	100
Indicated horse-power			High-pressure cards spoilt.			553
Steam weights, estimated from high-pressure indicator cards	lbs. per hour		,, ,,	,, ,,		8,140
,, ,, ,, ,, mean ,, ,, ,,	,, ,,	1,302	1,287	8,709	Spoilt.	7,878
,, ,, ,, ,, low ,, ,, ,,	,, ,,	1,617	1,302	7,050	7,080	6,610
Chemical Determinations.						
Salinity of feed-water samples	grains per gallon	85·9	86·0	21·2	19·9	22·7
,, ,, sea ,, ,,	,, ,,	1,750	1,728	1,977	1,892	1,877
Measured volume of sea water injected into air pump	gallons per hour	10·84	10·78	10·71	9·86	10·78
Estimated volume of condensed steam	,, ,,	210·0	205·3	988·0	927·7	880·6
,, weight of condensed steam per indicated horse-power	lbs. per hour	—	—	—	—	16·2
,, moisture in high-pressure cylinder	per cent.	—	—	—	—	7·5
,, ,, ,, mean ,, ,,	,,	38	37·5	11·8	—	10·5
,, ,, ,, low ,, ,,	,,	23	36·7	28·6	23·6	25·0

(the brine cock B was used in some cases and would do equally well). Both the cocks X and A were kept open for about five or ten minutes before each experiment, so that a

TABLE VI.

TIME READINGS AND JAR MEASUREMENT DURING THE TRIAL OF ENGINE A. (SEE TABLE IV.)

Reference Number	1.	2.	3.	4.
Mark on Jar.	Seconds.	Seconds.	Seconds.	Seconds.
0·65 gallons	0	41½	39	—
0·6 ,,	13½	55½	47½	—
0·55 ,,	27	70	57	12½
0·5 ,,	40½	83½	66	29
0·45 ,,	55	98	75	45
0·4 ,,	69	111½	84	52
0·35 gallons	83½	126	92½	69
0·3 ,,	97	140½	102	84
0·25 ,,	111½	154½	112	108
0·2 ,,	127	169	120½	124
0·15 ,,	141½	184	130	—
0·1 ,,	155	199	140	—
Sum of reading 0·65 to 0·4	205	460	368½	138½
,, ,, 0·35 to 0·1	715½	973	697	385
Difference	510½	513	328½	246½
Gallons per hour (see Table IV.) ...	12·68	12·62	19·72	11·70

small but steady flow of water from the sea took place, passing through the air pump into the feed pumps, from which a sample was now taken at the cock C. A sample of sea water was also collected, and the cock X was then closed, care being taken to see

that the jar J was full of water. The suction to the condenser being still open, the water-level in J would sink, and the rate of injection could easily be ascertained by noting the times at which the various marks on J were being passed. The actual readings for the four experiments on engine A are given in Table VI.

The collected samples were now chemically analysed, as will be explained later on, and the estimate of the volume of condensed steam was then a simple matter. Thus in the case of experiment No. 1, Table IV., it was found that the sample of feed-water contained 63·3 grains of salt per gallon, while the sea water contained 1,963 grains. The rate at which the condenser sucked the sea water out of the jar J was 12·68 gallons per hour (see Table VI.), and therefore the amount of steam condensed per hour was $12{\cdot}68 \times (1{,}963 - 63{\cdot}3) \div 63{\cdot}3 = 380{\cdot}5$ gallons, as stated in Table IV.

Generally speaking, the process is somewhat more complicated, because of possible leakages of the condenser, and priming. To estimate these, preliminary samples of feed and boiler water have to be collected before the injection is commenced. If the former are found to contain salt, corrections must be made which, although they are simple enough, introduce some uncertainty into the calculations, because one cannot depend on the leakages or priming being constant. No experiments with sea water in which any leakage was detected have been included, but in every case samples were taken both before and after starting to inject, in order to be sure that there was no leakage.

Measurement of Feed by Caustic Soda Injections.

For this reason, and because of the possibility which presented itself of also measuring the volume of circulating water, other experiments were made, in which the chemicals injected were, in one case caustic soda, and in another trial, carbonate of soda. The results of the caustic soda trials are given in Table VII., engine C, trials 10 to 14. Two jars were used on the trial, one for supplying the condenser and one for the circulating pump, but this arrangement did not work well except as regards the feed, for which the injected solution amounted to less than three gallons per hour. The supply to the circulating pump could not be maintained at a constant rate, because the jar had to be frequently re-filled by jugs, which left no time for accurate observations. During these trials, which lasted about two hours, the caustic soda solution took the skin off all my finger tips, and when carrying out the chemical determinations difficulties arose on account of precipitates being formed both in the feed and circulating water samples; it also interferes with the salt test, so that this chemical cannot be recommended for general use.

The results of this trial have been recorded because they were very carefully made, and the information thus gained may be of value. In this case the indicator cards were all satisfactory.

TABLE VII.

Engines C, 18 in. and 40 in. Diameter, 27 in. Stroke.

Reference number	10	11	12	13	14
Conditions under which the engines were worked	Throttled.	Full speed.	Linked up.	Linked up.	Throttle shut.
Time of commencing to inject caustic soda brine into the air pump	12.6 p.m.	?	1.4 p.m.	1.24 p.m.	2.26 p.m.
,, collecting samples of water and taking indicator cards	12.12 p.m.	?	1.10 p.m.	1.30 p.m.	2.32 p.m.
Steam pressure .. .. lbs. per sq. in.	124	115	102	92½	90
Receiver pressure .. .. ,, ,,	5½	10	9	8	1
Vacuum .. .. inches	25½	25	28	27	26
Revolutions per minute	98	101	88	80	74
Indicated horse-power	329	477	254	214	182
Steam weights, estimated from high-pressure indicator cards .. .. lbs. per hour	5,260	7,200	3,860	3,170	2,680
,, ,, ,, low ,, ,, ... ,, ,,	5,730	7,610	3,895	3,300	2,390
Chemical Determinations.					
Alkalinity of feed-water samples .. .. milligrams per 100 c.c.	43·62	29·77	51·60	53·75	59·38
,, ,, ,, ... ,, ,,	43·98	30·23	51·48	53·72	58·82
Mean values .. .. .. ,, ,,	43·80	30·00	51·54	53·735	58·60
Alkalinity of caustic soda solution diluted in distilled water (see Table X.) ,, ,,	8,820	8,820	8,820	8,820	8,820
Measured volume of caustic soda solution injected into air pump .. .. gallons per hour	3·11	2·845	3·002	2·830	3·145
Estimated volume of condensed steam .. .. ,, ,,	623·2	833·6	510·8	461·7	470·2
,, weight of condensed steam per indicated horse-power .. .. lbs. per hour	18·9	17·5	20·1	21·6	25·8
,, moisture in high-pressure cylinder .. .. per cent.	15·8	13·8	24·7	31·5	43·0
,, ,, low ,, ,, ... ,,	8·3	8·9	24·0	28·7	49·2

Measurement of Circulating Water by Soda Injections.

One of the objects of measuring the circulating water was to obtain a check on the feed-water estimate, which could be done by comparing the heat contained in the steam when it leaves the low pressure cylinder, with the heat which is carried overboard by the circulating water. The exact amount of heat which is thus wasted has not yet been calculated, but it is evidently less than that contained in the steam when it enters the low-pressure cylinder, but it may be more than the heat contained in the steam at its exhaust temperature. Reckoning from 32° Fahr. these two limits are about 1,150 and 1,130 thermal units. The moisture contained in the steam ought, perhaps, only to be credited with from 130 to 200 thermal units, unless the whole phenomena of moisture in the cylinders can be explained by initial condensation and final re-evaporation, in which case the total feed water (which includes the moisture), if cooled down to 32° Fahr., may be assumed to have parted with about 1,140 thermal units.

No experiments on this subject have been made on marine engines, and as regards land engines the feed and condensing water are rarely kept separate; and being mixed, they have to be measured together, and even when surface condensers have been used, only the feed which is supplied to the boiler, and not the condensed steam which leaves the engine, has been determined. The mechanical means employed for measurement are generally, tanks for the feed, and overflow weirs for the discharge water. Professor Osborne Reynolds carried out a large number of trials on his triple-expansion engine (Proceedings Inst. Civil Engineers, Vol. XCIX. p. 194), in which the above-mentioned quantities are recorded. The results are given in Table VIII. The

TABLE VIII.

Experimental Determination of the Amount of Heat Rejected per Pound of Steam used in the Experimental Triple-Expansion Engine at Owens College, Manchester.

Condition of working engine		Jacketed.			Unjacketed.		
Number of trial		44	33	56	41	35	40
Heat carried away by the circulating water per pound of steam condensed	thermal units	1,076	1,043	1,042	1,064	1,001	979
Temperature of hot well above 32° Fahr.	degrees Fahr.	70	82	81	76	82	100
Observed total heat contained in one pound of steam above 30° Fahr.	thermal units	1,146	1,125	1,123	1,140	1,083	1,079
Excess of observed heat over estimated heat	,, ,,	+ 64	+ 29	+ 31	+ 51	− 8	− 12
,, ,, ,, ,,	per cent.	+ 5·6	+ 2·6	+ 2·7	+ 4·4	− 0·7	− 1·1

TABLE IX.

ENGINES D, 15, 25½, AND 41 IN. DIAMETER, 27 IN. STROKE.

		Trial No. 1.	Trial No. 2.		
Reference number		15	16	17	18
Time of commencing to inject carbonate of soda solution		3.52 p.m. 4.10 p.m.	4.32 p.m.	4.32 p.m.	4.32 p.m.
,, ,, collecting samples of water, and taking indicator cards		4.15 p.m.	4.37 p.m.	4.42 p.m.	4.47 p.m.
Steam pressure	lbs. per sq. in.	160	145	—	—
No. 1 receiver pressure	,, ,,	58	48	No cards.	No cards.
No. 2 receiver pressure	,, ,,	8	6	,,	,,
Vacuum	inches	16¼	27	,,	,,
Revolutions per minute		103	101	,,	,,
Indicated horse-power		629·6	588·3	,,	,,
Steam weights, estimated from high-pressure indicator cards	lbs. per hour	7,800	7,460	,,	,,
,, ,, ,, ,, mean ,, ,, ,,	,, ,, ,,	9,010	8,810	,,	,,
,, ,, ,, ,, low ,, ,, ,,	,, ,, ,,	8,060	7,710	,,	,,
CHEMICAL DETERMINATIONS. SEA WATER.					
Alkalinity of circulating water samples, collected at discharge valve Y (Fig. 3)	milligrams per 50 c.c.	6·61	7·12	6·73	6·84
	,, ,, ,,	6·53	7·14	6·89	6·68
	,, ,, ,,	6·59	—	6·95	6·76
Mean values	,, ,, ,,	6·577	7·13	6·92	6·72
Alkalinity of circulating water samples, collected at condenser top X (Figs. 2, 3)	,, ,, ,,	7·03	7·25	6·85	6·84
	,, ,, ,,	6·98	7·29	68·2	6·97
	,, ,, ,,	6·97	7·20	—	6·91
Mean values	,, ,, ,,	6·993	7·247	6·835	6·94
Alkalinity of sea-water samples, collected at ash cock	,, ,, ,,	2·89	2·88	2·55	2·92
	,, ,, ,,	2·86	2·79	2 62	2·82
	,, ,, ,,	—	—	2·61	2·84
Mean values	,, ,, ,,	2·875	2·835	2·593	2·83
Alkalinity of sea water due to injected soda. Difference of two last mean values	,, ,, ,,	4·118	4·412	4·242	4·11
Alkalinity of carbonate of soda solution when diluted with sea water (see Table X.)	,, ,, ,,	2,975	2,975	2,975	2,975
Measured volume of carbonate of soda solution injected into circulating pump	gallons per hour	30·18	30·82	30·22	29·62
Estimated volume of circulating water	,, ,, ,,	21,770	20,750	21,170	21,410

TABLE IX.—(*Continued.*)

		Trial No. 1.	Trial No. 2.		
Reference number		15	16	17	18
Time of commencing to inject carbonate of soda solution		3.52 p.m. 4.10 p.m.	4.32 p.m.	4.32 p.m.	4.32 p.m.
,, ,, collecting samples of water and taking indicator cards		4.15 p.m	4.37 p.m.	4.42 p.m.	4.47 p.m.
Chemical Determinations. Feed Water.					
Alkalinity of feed-water samples	milligrams per 50 c.c.	4·16	3·85	4·29	4·76
	,, ,, ,,	4·27	3·75	4·31	4·91
	,, ,, ,,	—	3·79	4·32	5·00
Mean values	,, ,, ,,	4·215	3·77	4·315	4·955
Salinity of feed-water samples	grains per gallon	178·0	6·1	1·5	0
Salinity of sea water	,, ,,	1,972	1,943	—	—
Estimated percentage of supplementary feed water from sea	per cent.	9·94	0·31	0·08	0
,, alkalinity of feed water due to supplementary feed	milligrams per 50 c.c.	– ·1328	– ·00415	–·00103	0
Alkalinity of feed water due to injected solution	,, ,, ,,	4·348	3·811	4·316	4·955
Alkalinity of carbonate of soda solution when diluted with feed water (see Table X.)	,, ,, ,,	2,947	2,947	2,947	2,947
Measured volume of carbonate of soda solution injected into air pump	gallons per hour	1·437	1·323	1·322	1·321
Estimated volume of condensed steam	,, ,, ,,	972·5	1021·7	901·4	784·5
,, weight of condensed steam per indicated horse-power	lbs. per hour	15·4	17·4	—	—
Estimated moisture in high-pressure cylinder	per cent.	18·4	25·7	—	—
,, ,, mean ,, ,,	,, ,,	5·5	12·3	—	—
,, ,, low ,, ,,	,, ,,	15·6	23·2	—	—
Thermometer Readings.					
Feed water	degrees Fahr.	119·3	108·5	107·2	95·0
Circulating water condenser top X (Figs. 2, 3)	,, ,,	99·2	88·0	86·0	84·3
,, ,, discharge valve Y (Fig. 3)	,, ,,	95½	89½	88	85½
,, ,, condenser bottom Z (Figs. 2, 3)	,, ,,	45·9	45·7	45·9	45·7
Increase of temperature of circulating water	,, ,,	49·6	43·8	42·1	39·8
Discharged Heat.					
Heat discharged by total feed water (including supplementary feed) above 32° Fahr.	thermal units	933,380	784,020	678,390	494,230
,, ,, circulating water (the thermal capacity of sea water is 0·973)	,, ,,	10,507,820	9,116,230	8,669,470	8,291,490
Total heat discharged	,, ,,	11,441,200	9,900,250	9,347,860	8,785,720
,, ,, ,, per 1 lb. of feed water	,, ,,	1,176·5	969·0	1,037·0	1,120·0

excess temperature of the feed over the freezing point of water has been added by me, in order to make the readings comparable with my determinations. The last line of this table contains the differences between Professor O. Reynolds' experiments and his estimates, but I am unable to say how the latter were obtained. The point to which particular attention should be directed is the variation amongst the results; thus the highest and lowest values for the jacketed engines differ by 3·0 per cent., and those for the unjacketed engines differ by 5·5 per cent.

On referring to my last trials, recorded in Table IX., engine D, Nos. 15 to 18, last line, whose indicator cards are given on Plate XXXIX., it will be seen that the observed amounts of heat rejected per pound of feed water were, 1,176·5, 969, 1,037, 1,120. The first value, No. 15, may be slightly high, for although both injection-cocks were opened at 3.52 p.m., the one which supplied the circulating pump was accidentally closed again until 4.10 p.m., while that for the feed was full open all the time. The error cannot be a serious one, because it takes only fifteen double strokes of the circulating pump to fill all the water-spaces of the condenser. (See Condenser Section, Fig. 2, Plate XXXVIII.) The engine having accidentally been stopped between Nos. 15 and 16, it is reasonable to assume that water had accumulated in the cylinders, which accounts for the low results in Nos. 16 and 17 and perhaps even No. 18: the latter was measured about twenty minutes after re-starting. As these experiments (Table IX.) may be considered entirely successful, the following detailed description of the proceedings will be of interest.

A large tank T which is partly shown in section, Fig. 3, Plate XXXVIII., was placed near the pumps. It was filled with 2 cwt. of washing soda, and hot water, and very thoroughly mixed, as was proved by chemical analysis of five samples, taken at 3.52, 4.32, and 4.50 p.m. (see Table X.). A wooden float F, was laid on the solution, and a light wooden gallows *g* secured to it. This supported two indiarubber tubes *m* and *n*, whose ends, which were bent glass pipes of $\frac{1}{4}$ in. and $\frac{1}{8}$ in. diameter, were thus always kept at a definite distance below the fluid level, F, in the tank, whereby a very constant flow was secured. The other end of the tube *m* was connected to a $\frac{5}{8}$ in. cock *c*, at the bottom of the tank, and *n* ended in a brass tube syphon pipe *s*, whose lower end was placed at exactly the same height as the cock *c*, so as to ensure that the same quality of soda should be supplied to both. The result was satisfactory (see Table X.). Samples No. 2 and 4 were taken from *n*, while Nos. 1, 3, and 5 came from *m*. The quantity of liquor which flowed out of either tube was measured as follows: For *n*, a glass flask was used; it had a funnel mouth (Fig. 4, Plate XXXVIII.), and was carefully graduated up the neck, the lower reading being 100 c.c., or about 4 oz., and the upper reading 105 c.c. It required about one minute to fill this flask. In order to measure the liquor which flowed out of *m*, a one-gallon tin was altered, as shown in Fig. 5,

TABLE X.

Chemical Determinations of the Alkalinity of the Solutions used in Experiments C and D.

Engine C (see Table VII.).									
Caustic Soda Solution diluted in									
Distilled Water.					Sea Water.				
Sample Volumes.		Alkalinity.			Sample Volumes.		Alkalinity.		
Distilled Water.	Soda.	Observed.	Mean Value.	Difference.	Sea Water.	Soda.	Observed.	Mean Value.	Difference.
c.c.	c.c.	m.g.	m.g.	m.g.	c.c.	c.c.	m.g.	m.g.	m.g.
100	0·1	8·88	8·82	+·06	100	0	5·45	5·45	0
100	0·2	17·60	17·64	−·04	100	0·1	14·32	14·31	+·01
100	0·3	26·50	26·46	+·04	100	0·2	23·16	23·17	−·01
100	0·4	35·28	35·28	0					
100	0·5	44·07	44·10	−·03					
100	0·6	53·00	52·92	+·08					
Mean, 8,820 milligram per 100 c.c.					Mean, 8,860 milligram per 100 c.c.				

Engine D (see Table IX.).																									
Carbonate of Soda Solution diluted in																									
Distilled Water (Various Samples).						Feed Water (Sample No. 1).					Sea Water (Sample No. 1).				
Sample Number.	Sample Volumes.		Alkalinity.			Sample Volumes.		Alkalinity.			Sample. Volumes.		Alkalinity.		
	Distilled Water.	Soda.	Observed.	Mean Value.	Difference.	Feed Water.	Soda.	Observed.	Mean Value.	Difference.	Sea Water.	Soda.	Observed.	Mean Value.	Difference.
	c.c.	c.c.	m.g.	m.g.	m.g.	c.c.	c.c.	m.g.	m.g.	m.g.	c.c.	c.c.	m.g.	m.g.	m.g.
1	50	0·1	5·78	5·78	0	50	—	·06	·06	0	50	—	2·75	2·77	−·02
1	50	0·1	5·76	5·78	−·02	50	—	·05	·06	−·01	50	—	2·85	2·77	+·08
2	50	0·1	5·74	5·78	−·04	50	0·03	1·81	1·78	+·03	50	0·02	3·95	3·96	−·01
2	50	0·1	5·80	5·78	+·02	50	0·03	1·81	1·78	+·03	50	0·02	3·98	3·96	+·02
3	50	0·1	5·90	5·78	+·12	50	0·06	3·58	3·59	−·01	50	0·04	5·16	5·16	0
3	50	0·1	5·76	5·78	−·02	50	0·06	3·58	3·59	−·01	50	0·04	5·27	5·16	+·11
4	50	0·1	5·80	5·78	+·02	50	0·09	5·35	5·36	−·01	50	0·06	6·27	6·35	−·08
4	50	0·1	5·74	5·78	−·04	50	0·09	5·37	5·36	+·01	50	0·09	7·50	7·54	−·04
5	50	0·1	5·82	5·78	+·04										
5	50	0·1	5·75	5.78	−·03										
Mean, 2,890 milligram per 50 c.c.						Mean, 2,947 milligram per 50 c.c.					Mean, 2,975 milligram per 50 c.c.				

Plate XXXVIII., by having a funnel mouth soldered to its neck, of which the inside was graduated. The lowest mark was 5,020 c.c., and the highest 5,070 c.c. It took about two minutes to fill this tin. In either case the contents of the flask or jar could be read off to within one-tenth per cent. of the total volume, and the time of filling could be read off to within one-fifth second, so that the maximum error of these measurements could not exceed $\frac{1}{4}$ per cent.

During the first experiment of this last trial the cock *c* was accidentally closed, which was not discovered until five minutes before taking the samples of trial No. 15, and then unfortunately the engines were unexpectedly stopped by the captain. In the second experiments Nos. 16, 17, and 18, the rates at which the soda flowed out of *m* and *n* were determined before starting and after ending; they were 30·52 and 1·323 gallons per hour at the commencement, and 29·92 and 1·321 at the completion of the experiment. The slight change in the flow was due to a gradual but perfectly marked tilting of the float F, and could in future be guarded against. The measurements were made by holding either the flask or the gallon tin under *n* or *m* and noting the exact time of filling, and then removing them suddenly; the liquor would then pour into the two funnels *p* and *r*, which were connected, by $\frac{5}{8}$ and $\frac{1}{4}$ in. lead pipes respectively, to the snifting valve V of the circulating pump, and to a cock A under the air pump, the latter being opened only very slightly, so as not to admit an unnecessary amount of air. As soon as the experiment was completed the flask and tin were once more held under the tube-ends of *m* and *n*, and new determinations of the rate of flow were made.

Water-meters have unquestionably been brought to a high state of perfection, but none give correct readings if air should get mixed with the water, as is sure to be the case in a marine engine, unless the feed pump is worked automatically, and unless the circulating pump is driven by a separate engine. In my experiments, however, the trouble to be expected with a meter, if used for measuring the flow of liquor, was not that air would get into it, but that its frictional resistance would produce an irregularity in the supply. In fact, the only practical plan of using a meter would be to couple it to the engine, and thus drive the liquor into the feed or circulating water, making the necessary allowances for leakages.

The sampling of the various waters was done with the greatest care. One sample was taken from the ash cock after first thoroughly clearing the pipe, another was taken slowly from the feed pump. Two samples were taken of the circulating water, one from the cock X (Figs. 2 and 3) on the condenser top, the other was caught up by a bucket at the discharge valve Y. Apparently one sample would have sufficed, but as the water at Y had to be collected by swinging a bucket into the descending stream, there was a possibility of catching a portion containing either too much or too little soda, because, on account of the intermittent action of the circulating pump, and its large volume as

compared with the condenser spaces, one might expect slight irregularities in the distribution of the soda *along* the stream, which would disappear in a sample collected slowly at X. As regards the discharge water temperatures, the conditions are evidently reversed; the irregularities are not likely to be found *along* the stream, but *across* its section, and the cock X might occupy a position where it would draw off only that water which has passed through the top rows of tubes, and which would naturally be the hottest, or it might draw off a colder stream. However, when these various streams have passed through the discharge valve, they will be well mixed, and by swinging the bucket into the full stream at Y a fair average temperature sample would be obtained. These views are fully confirmed by the chemical and thermometric readings of both sets of samples, which are all recorded in Table IX., but have not all been used in the subsequent calculations.

In order that these temperatures might be read ofi with the greatest care, four tinplate quart pots were fitted with small split tubes (see Fig. 6, Plate XXXVIII.), into which the thermometers were inserted: any danger of cooling the thermometer while taking its reading was thereby removed. The water in each quart pot was then poured into a bottle and subsequently analysed. All the thermometers had been compared and their readings corrected. The divisions were sufficiently large to allow of tenths of degrees Fahr. being read off, but this was not done for the samples collected at Y. The temperature of the sea was read off from a sample collected at the condenser bottom cock. The samples for Nos. 16 to 18 were taken in the River Clyde between Gourock and Greenock.

Chemical Determinations: I. Salt Tests.

In the experiments which have been detailed in Tables I., IV., and V., the nitrate of silver test for salt was used. A large stock solution was prepared of nitrate of silver and distilled water (about 120 grains to the gallon), from which the accurately graduated burette B (Fig. 7, Plate XXXVIII.) was replenished. The sample of water to be tested was poured into the beaker A, to which a few drops of a strong solution of yellow chromate of potash had been added. All the sea water samples were first diluted down to the strength of the salted feed water. A reading was now taken of the upper level of the nitrate of silver solution, of which as much was then run into the beaker as would just cause the sample to change its colour from a pale yellow to a reddish brown. With a little practice this could be done with the greatest nicety, as is shown by the readings of the salinity of Glasgow town water, in which there were only 1·3 grains of salt per gallon. The change of colour could not be read with the same precision when there were larger percentages of salt, because of a heavy milky precipitate of silver chloride. Table XI. contains the actual readings of the chemical tests for engine

A (Table IV.). In no case do they differ by more than ¾ per cent. from the mean values. For fairly accurate and rapid determinations this test cannot easily be surpassed, but in inexperienced hands there is always a danger of obtaining too high a reading, because the change of colour must have taken place before it is noticed. To minimise this danger the sea water samples were diluted down to the strengths of the feed waters with which they had to be compared. The error of 5 per cent. in Table I.,

TABLE XI.

Burette Readings of the Nitrate of Silver Test on Eight Samples of Water for Engine A, Table VI.

	Sea Water.				Feed Water.			
Reference number... ...	1	2	3	4	1	2	3	4
Volumes tested	2 × 1 c.c.	2 × 1 c.c.	2 × 1 c.c.	2 × 1 c.c.	4 × 10 c.c.	4 × 10 c.c.	4 × 10 c.c.	4 × 10 c.c.
	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
Burette readings	2·95	1·80	2·00	2·05	2·50	0·25	1·90	1·75
,, ,, ...	68·00	66·95	66·85	67·55	23·15	23·60	25·80	31·20
,, ,, ...	0·00	4·55	1·35	3·85	44·15	46·75	50·00	60·40
,, ,, ...	64·75	70·05	66·10	69·25	65·10	69·90	74·40	89·40
Mean values	64·90	65·27	64·80	65·45	20·90	23·20	24·17	29·02
Grains of salt per gallon ...	1,963	1,974	1,960	1,980	63·3	70·2	72·9	87·9

if it is not due to leakage as explained, may be put down to this cause, for it only amounts to 0·065 grains per gallon, which would affect the burette readings by only 0·025 c.c.

Mr. Volhardt's Method.—A more accurate test for salt is the following :—Prepare a weak aqueous solution of nitrate of silver and nitric acid, also a weak solution of sulphocyanate of ammonia: the two fluids should be of equal strengths. A preliminary determination of the salinity of a small portion of the sample is made as described, then a carefully measured volume of the sample is mixed with a carefully measured volume of nitrate of silver solution, but slightly more than required, so as to precipitate all the chlorides. This sample is put aside for a day in a dark place, and the clear

fluid is drawn off and tested with the help of the above standard solutions. A drop or two of ferric alum salt index is first added, and then the sulphocyanate is titrated into it out of the burette until a change of colour takes place. If this is too marked, a little nitrate of silver solution is added, and this zigzag titration continued until the neutral point has been reached. The differences of the readings of the two burettes are then subtracted from the volume of nitrate originally added to the sample, and the remainder is the exact volume of the weak nitrate of silver which was required to neutralise the salt in the sample. Both the above-named tests ought to be carried out by artificial light. The clearing is not necessary with weak salt waters.

II. Alkali Test.

Many substances are known which change colour if transferred from an acid bath into an alkali one, but for the determination of the alkalinity of sea water nothing is likely to surpass aurine as an index if used as recommended by Mr. Tornö.

Weak solutions of hydrochloric acid and water, and of caustic soda and water, are prepared, the two being made exactly equal in strength. They are poured into two burettes (B, Fig. 8, Plate XXXVIII). A carefully measured volume of the water sample to be tested is poured into the Berlin bowl C, a few drops of aurine, dissolved in water, are added, and the whole is then boiled over a Bunsen burner F. The colour of the fluid will at once change from an imperceptible pale amber to a beautiful rose pink; measured quantities of hydrochloric acid are from time to time added from the burette until the rose colour has permanently disappeared, which is a sign that the hydrochloric acid is in excess. Boiling is necessary in order that all the carbonic acid in the sea water, both free and combined, may be driven out. Drop by drop alkali solution is now added, until the pink colour returns, then acid is added until it just disappears. The difference of the loss of solution from the two burettes is a measure of the alkalinity of the sample. A second sample from the same bottle is now measured out, and a slight excess (about one per cent.) of acid solution added, the boiling is proceeded with for about fifteen minutes, and then the neutralisation is effected as before. If this determination did not agree with the first one, I took another sample and rejected the first. All the actual readings are recorded in Tables VII., IX., and X. In the first experiments, Table VII., and part of Table X., several precautions had been omitted, and these results are therefore not as uniform as they might have been.

During the progress of these tests it was frequently noticed that the levels of the fluids in the burettes had changed, once even as much as ·15 c.c., although no fluid had been drawn off. This was found to be due to the gradual heating of the fluid in the burette on account of its proximity to the Bunsen burner. To remove the burettes

after each slight addition would have been troublesome, and might, during the fifteen minutes of boiling, have led to an occasional loss of a drop of acid or alkali, which would have affected the results by 1 per cent. The final arrangement adopted was that shown in Fig. 8; in which a long, fine glass tube *g* reached from each burette to the Berlin bowl.

The strengths of the acid and alkali solutions were those adopted by the late Professor W. Dittmar, viz., each cubic centimetre contained as much caustic soda as would exactly neutralise 1 milligram of carbonic acid. These are the units adopted in the tables. Experiments which were subsequently carried out by me, with solutions having only one-tenth of the above strength, proved that a change of colour of the aurine index was quite perceptible on adding only ·01 c.c. of the standard fluid, a quantity which affected the levels in the burettes by less than $\frac{1}{400}$ in. However, having commenced the chemical determinations before I was fully aware of this extraordinary accuracy, I did not venture to dilute the fluids, and all the readings are made with the normal strengths.

A still more accurate determination than any to be found in this paper could have been made, if, instead of salt or soda, the rather expensive chemical, nitrite of soda, had been injected into the waters. The accuracy attainable with this substance is such, that the capacity of one of the Tilbury graving docks, holding about 60,000 tons of water, could be determined chemically to within 1 per cent. of its true amount, if only 1 cwt. of nitrite were to be dissolved in the water, of which a few ounces would suffice for the analysis, which is a colourimetric one. The experiment would cost about £20.

With the experience that had been gained by sea injections into feed water to guide me, I was afraid that soda solutions would produce chemical changes that might interfere with my tests; and, in order to be quite independent of such influences, the solutions which were used have been chemically tested when diluted down to the experimental strengths, either with feed water or with sea water (see Table X.), and the results have been used as standards of comparison in Tables VII. and IX. The tests on mixtures of feed water, and soda sample No. 1, are carried out with every conceivable precaution, except that the titrating fluids were not diluted, and are, as will be seen, highly satisfactory. It will be noticed that in Table IX. a separate chemical determination of the salinity of the feed water has been made; this was only possible when using carbonate of soda injection, but was necessary because of the supplementary feed being partly open until 4.15 p.m. As will be seen, the sea water thus introduced had not been entirely washed out even after half an hour's run. For this reason several of my experiments, based only on the salt test,

have not been included in this paper, for I could not feel sure as to whether the detected leakages were real ones.

A notice will be found in Table IX. that the thermal capacity of sea water is 0·973. No direct experiments on the subject seem to have been made, but I discovered some by Mr. Schüller (Poggend. Ann., Vol. CXXXVI.) on the specific heats of salt solutions, from which the above value has been estimated. The specific heat of chloride of soda is 0·21401, and the density of sea water has been assumed to be 1·026.

Conclusions.

Having demonstrated the accuracy of this chemical method of estimating water quantities, it only remains to point out the advantages which can be obtained by its use.

(1) The circulating water of a marine engine can be measured at sea: this has not been done before. The quantity of carbonate of soda (washing soda) required is approximately 2 cwt. per 1,000 I.H.P. per hour, which should be dissolved in a tank of fresh water holding about 60 gallons. (A sample of about 300 c.c. is ample for the test.)

(2) The feed water of marine engines, not fitted with slow working automatic pumps, can be measured either by injecting carbonate of soda solution or sea water. On account of the air which is mixed with the feed water when the pumps are worked by the main engines, mechanical feed meters would not give accurate results under such conditions.

(3) The method can be applied to the accurate measurement of the volume of water in small streams, and would be of special value in a mountainous district. It being possible to determine the salinity of water, holding only 1 grain per gallon in solution, to within 1 per cent. of its true amount, it would be necessary to add salt brine (containing 50 oz. to the gallon) at the rate of only 1 gallon per minute to a stream which delivers 350 gallons of water per second, and to collect a sample after thorough mixing has taken place. The measurement of the volume of water supplied to towns for drinking purposes is frequently done by weir gaugings, which are said to be unreliable to the extent of 5 per cent.

In conclusion, I beg to thank Messrs. R. Napier & Sons, Messrs. Ross & Duncan, Messrs. Muir & Houston, Mr. C. M. Aikman, Mr. R. J. Beveridge, Mr. Sinclair Couper, Mr. D. Johnson, and Mr. J. Thom for their assistance during these experiments, which have now extended over a period of two years, and have entailed an amount of labour which is only faintly indicated by the five trials that have been submitted in this paper.

DISCUSSION.

Mr. Schönheyder (Visitor) : I was very much interested in the paper by Mr. Stromeyer, and it seems to me that the method he proposes may be of use if you want to measure large quantities of water, such as the circulating water discharged from marine engines ; as it is, we have some difficulty in measuring it. You cannot apply an ordinary water meter, but there are certainly other means ; for instance, you may use a weir for that purpose—not the ordinary open weir, but a drowned weir connected with a special tank for the purpose of measuring accurately the height of water on the weir. This mode of measuring has this great advantage over a chemical method, that you can, at any moment, see the quantity of water being discharged from the weir, whereas, if I understand the paper rightly, you have to take certain samples of the discharged water and chemically analyse it. That must necessarily take a considerable time, or some time, at any rate, and you lose by that means quantities discharged at certain specified intervals. For measuring the ordinary feed water, I do not think this method will ever come into general use, or that it will be preferred to the ordinary mode of measuring by a proper and correct water meter ; first of all, on account of the difficulty, I have just mentioned, of having to wait until you get an analysis made of the discharge water. Then it seems to me it is not always very reliable, for I find in the paper the author makes mention of nearly as much as 5 per cent. having been found in one of his tanks, which is far too great an error to have in measuring feed water. There is the great advantage in measuring with a meter that you can see, at any moment, the quantity of water you are passing into the boiler, so that you can ascertain the quantity consumed between certain stations, or the quantity used when going against the wind and tide, or with the wind and tide. Of course, in making use of the meter for measuring feed on board ship you have to take care to have such an apparatus as will not be interfered with by the rolling or pitching of the ship. On land it is different, of course. As to accuracy of measurement, I have, from great experience in this direction, found no difficulty whatever in getting an accuracy of 1 per cent. in the registration, which is quite near enough for all practical purposes. In using the meter you have the great advantage that it can be read by the ordinary engineer in charge, and you are not obliged to carry a chemist on board for that purpose. He can read it when he pleases and when he thinks most necessary, and he need not read it at special intervals. As to the inaccuracy in obtaining readings, which the author speaks of, on account of the air in the water, I found no difficulty with regard to that. In all meters for measuring feed water for boilers, I provide, at the top of the casing, a valve which can be opened if any air exists in the water. By keeping this valve continuously open when it is found necessary, you can discharge the air continuously. As the water which is discharged with the air is not brought through the measuring apparatus it does not in any way invalidate the experiment. This water can be returned to the suction cistern and pass through the meter again. Of course, in certain arrangements of feed there is an excessively large amount of air passing through the feed water. I would, in such cases, construct a separate vessel in which the air could be allowed to separate from the water and there discharge it, so that there need not be any difficulty whatever on that point. As a matter of experience I may mention that I found no difficulty in measuring hot water; I have measured it as high as 296° Fahr., and found no difficulty at all.

Mr. J. T. Milton (Member of Council) : My Lord, I would only say a few words with regard to this paper generally. I think we should thank Mr. Stromeyer for bringing it before us. I do not know that he wishes to imply that the method would be of practical utility to be fitted to all marine engines, but he certainly is the first to show a practical means of measuring the quantity of

circulating water in a marine engine. This is an exceedingly difficult matter, from the enormous quantity of water used. No methods of metering, that I am acquainted with, would deal with such quantities. With regard to the degree of accuracy, the last speaker said it was not a very accurate measure, because in one particular case he found Mr. Stromeyer admitted an error of a possible 5 per cent. But I think if you look into that matter the actual test that Mr. Stromeyer gives is quite convincing that it is an exceedingly accurate means of determining the quantity of water. He mentions particularly, with regard to that 5 per cent., that it was a test to determine the quantity of feed-water supplied to some boilers fed by Glasgow water, and he mentions again that Glasgow water, "which is considered to be one of the purest drinking waters, contains only between one and two grains of salt per gallon." Now I think a test that can be applied by means of the small amount of salt in such water as that, with only one or two grains per gallon, and yet give a result within 5 per cent., is an exceedingly accurate one. We can see at once if the Glasgow water had been absolutely pure, and had not those one or two grains of salt per gallon, there would be no means of testing the quantity at all. If a more impure supply of water had been used in the boiler we should not have had the difference of 5 per cent. Taking it all round I do not think the paper is one that lends itself to discussion. It, however, indicates a means that has never yet been adopted for a similar purpose.

Mr. J. Thom (Member): I happened to be on the trial of the steamer mentioned when they were measuring the circulating water; in fact, I was told off to catch the water at the ship's side and find the temperature, as described by Mr. Stromeyer. I do not think it was ever intended that this method should be used as an everyday means of measuring the amount of circulation water. It is not necessary to have it taken every day, but only for scientific purposes. This is a very simple method for, say, measuring the circulating water on an Atlantic liner, whereas if you had to supply a water meter I do not know if you could get one, right away, big enough; besides, the expense of the altering of the pipes would be very great. I am very much surprised that the results are as accurate as shown by the table, because the steamer was required to stop at a pier in the middle of the trial. I think the paper will be of great service to us, and we ought to be very much obliged to Mr. Stromeyer for the great amount of work he has bestowed on it.

Mr. A. J. Durston, C.B. (Member of Council): My Lord and Gentlemen, may I be allowed to add my thanks to those already given to Mr. Stromeyer for the able suggestions contained in his paper. The matter appears to me one of great importance, as enabling an engineer to quickly test the efficiency of his engine under various conditions of working, and thus not only keep its working at a much higher rate of efficiency than he has the opportunity of doing at present, but also gain much information on these various conditions of working which will be of great service to the designer, and tend to heighten the interest taken by the engineer in the machinery under his charge. The number of ships of our Navy the machinery of which is under the care of my brother engineers is my excuse for intruding these few remarks.

The following reply was communicated by Mr. A. C. Stromeyer (Member), who was not present during the reading of his paper:—

In reply to the discussion, I would like to remark that the friendly criticism which has been passed upon my paper has shown me how much it has been appreciated, even although it is evident that the large number of experiments detailed therein, for the purpose of proving the accuracy of the new methods, has, to some extent, obscured its object; which was, to explain how to measure the volume of the circulating water with such accuracy, that one would be able to determine whether the

large percentages of moisture in steam, which are found in all trials where the indicator cards are compared with the feed meter readings, are due to priming, or to initial condensation and re-evaporation. In the latter case the heat carried away by the discharge and the feed-water ought to be equal to that contained in the saturated steam which enters the high-pressure cylinder, less the heat lost by radiation and less the heat equivalent of the indicated work. Experiment No. 18, of Table IX., supports this view, but, being a single one, it would require further confirmation. The numerous other experiments, both on the feed supply to land boilers and to marine boilers, are simply intended to demonstrate the accuracy and simplicity of the chemical method, and have not been marshalled, as has been supposed, for the purpose of discrediting mechanical feed meters for use in steamers. On the contrary, I am one of their strong advocates, believing, as I do, that they would soon lead to large reductions of the coal bills; but, as very few merchantmen, and no warships, have been fitted with meters, my method might with advantage be used occasionally, just as the indicator is used occasionally; and, as the chemical tests are simple, and could be carried out at sea, engineers would thus be able rapidly to ascertain for themselves the best conditions of working their engines. The coal consumption on torpedo-boats is a subject which is daily receiving more and more attention, both from the Admiralties and from the builders, and as it is quite out of the question to fit heavy meters in such boats, my method could readily be used there for experimental purposes. Doubts have been expressed as to the accuracy of the test, but these are not shared by chemists, and my own experience is that, the nitrate of silver test will determine the amount of salt in solution to within one five-millionth; but, as the Glasgow town water of the experiments, detailed in Table I., contained 1·3 grains of salt per gallon of water, or about 1 in 50,000, the chemical tests ought to be accurate to within 1 per cent. The difference of 5 per cent. between the meter readings and my determinations, to which Mr. Schönheyder drew special attention, must therefore be due to other causes than inaccuracy in the chemical test, and the most probable one is that explained on page 328, viz., a constant leakage from the boiler of 0·4 per cent. is sufficient to account for the whole loss of salt. Had the trial been continued for several weeks under the same conditions of leakage, then the saltness of the boiler water would have decreased at an ever diminishing rate, until it reached a minimum of 325 grains per gallon, or about ½ per cent.; at this density the 0·4 per cent. of leakage would carry away exactly as much salt as was being added in the feed. This was, in fact, my first experience; the boilers having been in use for several months, contained far too much salt, and the method could not be applied until the boilers had been emptied and refilled with fresh water.

The President (the Right Hon. the Earl of Hopetoun, G.C.M.G.): Gentlemen, that concludes the discussion, and I beg to propose that a vote of thanks be accorded to the gentleman who has contributed this excellent paper.

SALVAGE APPLIANCES.

By J. G. Kinghorn, Esq., Member.

[Read at the Thirty-seventh Session of the Institution of Naval Architects, March 26, 1896; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

The object of this paper is to draw the attention of the members of the Institution and the nautical world to improved appliances for dealing with salvage operations, and supplying a means of grappling with the lifting and floating of stranded and sunken vessels, which, with the present inefficient plant, is in many instances impossible.

Prominent as Great Britain is in maritime affairs, it is strange that in one of the most useful and necessary branches, she should lag so far behind; because, whilst every department connected with ships and shipping, such as the building, propelling, life-saving appliances, coast lighting, harbours, graving docks, &c., have made great strides during the last quarter of the century, the appliances (with the exception of those of the port of London) which the salvage engineer has to employ, remain practically the same that were in existence when the first iron ships were launched, with the result that hundreds of thousands of pounds worth of ships and cargoes are lost beyond recovery every year on the coasts of the United Kingdom and Continent, consequent on the want of efficient plant to salve them, as the steam pumps and diving gear are the principal appliances which Continental nations or ourselves have to rely on in case of disaster to their naval or mercantile fleets. The steam pump and diving gear are no doubt invaluable appliances, as wonders in marine salvage have been accomplished by their aid, and that they will always be necessary in future operations there can be no doubt. But, valuable as their aid will always be, their utility is necessarily circumscribed and fettered. For instance, before the steam pump can be of any service, all holes admitting water to the vessel must be stopped, sufficiently at least to allow the pumps to overcome the leakage. Before the holes can be so closed or covered, the diver must be able to get to them. It is evident that this cannot be done in many cases from the outside of the ship, therefore cargo, or other material, if in the way, has to be removed, and the leaks reached by the diver from the inside; but even this is sometimes impossible, as in cases where the hole or holes are underneath the boilers or machinery. In any case the operations are, as a rule, of a very costly nature, and are

very tedious, and sometimes, after everything may have apparently gone on successfully, the ship may founder when she is pulled off the shore, carrying all the salvage gear with her; or, before she is ready for floating a gale springs up, and all is lost.

So far, I have only treated of casualties where the pump and diver have been most successful, viz., vessels which have been stranded and the bottoms punctured, or vessels which have been in collision, and run ashore to prevent foundering; and, where the holes can be readily reached by the diver, the pump is undoubtedly an efficient method, and in some cases might be the most economical and quickest mode of salvage. But the number of vessels so placed is comparatively small in the great bulk of marine disasters. I presume you will all agree with me that one of the most common causes of casualties, in and about harbours, rivers, and frequented channels is collision, and when one or both vessels sink, unless the decks of the vessels are dry, or nearly so, the universal practice is, where removal is imperative (except in the Thames) to destroy them by gunpowder or dynamite, precisely as the hull of the *Royal George* was disposed of over fifty years ago; and it is for the salvage of vessels sunk in depths in which divers can work that these appliances have been specially devised. At the same time, their use in supplying the necessary displacement to stranded ships of large size, where all of the compartments are not damaged, also in the case of smaller vessels, furnishing all the displacement necessary, according to the sizes of the camels used, cannot be overrated, yet the principal object of the inventions is the salvage of vessels sunk in depths up to 25 or 30 fathoms, the displacement of the camels and the number of ropes passed being the governing point of the weight they can lift.

As I have already stated, the Thames Conservancy possess the best lifting camels in existence, and all vessels sunk in their waters are lifted by these camels, but even their plant was (I am informed) taxed to nearly its utmost in lifting the SS. *Durham* some months ago. This steamer was estimated to weigh 1,400 tons in water. The whole efficiency of the plant of the Thames Conservancy is derived from the rising of the tide, and would therefore be next to useless where there was no rise or fall of water.

I will now proceed to describe the new appliances and the mode of working. To overcome the want of adequate tidal range on some parts of our own and Continental coasts, and in the Mediterranean, where there is a nearly total absence of rising water, the winch (Figs. 11,12, and 13, Plate XLII.) has been devised. For it the following advantages are claimed. It will grip a steel wire rope of large size at any given point; it will not injure the rope. It will heave any weight the rope can stand, slowly and steadily, will pay out rapidly, and register the weight borne by the rope on a suitable indicator gauge. It has a revolution counter, and the indications of the weights and revolutions are electrically reproduced by suitable instruments at a common centre, say, a bridge house, on any one of the camels, thus enabling the salvage engineer to

have full control of the lifting power at his command, and a perfect knowledge of the strain on each and all of the wire ropes.

Now, referring to the drawings (Figs. 11, 12, and 13), the winch consists as follows:—On the base plate a are two lower frames b, and two upper frames b^1. These frames support the ends c^1 of the hollow winding barrel c, on one end of which is a reel c^2 by which the unused portion of the rope is carried. The barrel c is worked by worm wheels d fixed on such barrel, and worms e engaging with and driving them; these worms being worked by worm wheels f on the shafts e^1, driven by worms g mounted on the shaft g^1, said shaft being rotated by a worm wheel h thereon, driven by a worm i supported in one of the flanges b^1, and driven by the bevel wheels j from the shaft k; this shaft being revolved by suitable power.

When starting, in the lifting action of the winch, little or none of the rope will be on the barrel; the part connected to the body to be moved would be tight, the remainder being on the reel c^2. The rope is passed to the reel c^2 from the barrel by way of a hole c^3 of gradual curvature, and over two grooved internal guides c^4 of suitable curvatures (see Fig. 14, Plate XLII.), by which, when tension comes upon the ropes, friction is created, and assistance to the holding afforded. Between the guide c and the reel c^2, there is a wire rope-gripping device i (Fig. 14) of a suitable kind, by which the actual holding and making fast of the rope is effected. From here, the rope passes over and is wound loosely on the reel c^2 (Fig. 12), this being the unused portion of the rope. The lead of the rope from the barrel c to the reel is nowhere bent or turned at such an angle as to injure the rope; that is, the turns being easy and gentle, the rope cannot possibly be damaged by the gripping in the machine.

It will be seen that, as the barrel revolves, the unused portion of the rope revolves with it.

The main driving worms e have their shafts e^1 (Figs. 11 and 12) vertically mounted, and the lower ends provided with rings e^2, fitting in corresponding thrust-block grooves in the part b^3 of the frames b. These blocks take all the strain which comes upon the worms shaft e^1. A modification of these supports is illustrated in Figs. 15 and 16, Plate XLII.; in these the shafts e are supported hydraulically, and the pressure on them indicated by an indicator. In the construction shown, the collars e^2 work in and are carried on a block p, made in halves, and prevented from rotating by a key q^1 on the retaining bracket q; and the lower end of the shaft e^1 and block p rest upon a piston r working in a cylinder s in the bed-plate a of the winch. The cylinders s are connected together. The shaft e^1 is mainly kept in position vertically by the cap v, only a small amount of movement is allowed to the shaft e^1. The small amount of movement of the piston is governed by the space t between the upper ring e^2 and the metal above it. The shaft e^1 is raised or lowered by a screwed plug u,

which screws in and out of the cylinder u^1, which is connected to the cylinder s by a passage u^2, and is filled with oil. The pressure on the shaft and piston, and so on the lifting ropes, is indicated by a suitable pressure gauge on the cylinders s or u^1, showing the weight in tons carried by the winch. By these means the pressure and strain on the two sides and shafts of a winch can be ascertained and regulated, and when several winches are used together for raising a single body of great weight, as when raising a ship, the strain on the different machines acting upon it can be seen at once by means of gauges electrically connected with the bridge house; also gauges from the gearing on the winches would have electrical connection to gauges in the bridge house, indicating the number of revolutions performed by each machine, thus enabling the salvage engineer in charge to have complete control of the whole lifting by the machines.

The gear between the worms e and the motive power is not restricted to that shown, but may be varied according to circumstances; nor is the invention (although the construction shown is a convenient one, and may be used with advantage) restricted to the particular form or arrangement of parts given in these drawings.

I will now proceed to describe the camel. With reference to the drawings. Fig. 1, Plate XL., is a plan; Fig. 2, Plate XL., is a cross-section of the camel or pontoon, and of the ship to be raised; Fig. 3, Plate XL., is a cross-section showing the position of the pontoons for raising a ship not completely submerged, and small submerged vessels can be lifted in deep water in the same manner; Fig. 4, Plate XLI., is a plan of a pontoon to a larger scale; and Figs. 5 and 6, Plate XLI., are longitudinal sections, and Fig. 7, Plate XLI., a cross-section of pontoon at the lines A A, B B, C C, respectively, in Fig. 4; Fig. 8, Plate XLII., is a sectional elevation of the bollards and sluice valves; Fig. 9, Plate XLII., is a plan of the sluice valves, and Fig. 10, Plate XLII., a cross-section of sluice or section valves and conduit controlled thereby, connected with pumps for emptying and filling the different compartments of the pontoon.

On either side of the ship to be raised we employ pontoons a, in most cases four, arranged as indicated in Fig. 1. According to this invention, the pontoons are provided with transverse wells b, running through two-thirds of the beam of the vessel, by which construction the ropes c, by which the vessels are lifted, can be taken up vertically from the ship to and through the pontoons, and a direct pull or strain is put upon the pontoons; and no matter what the width of the sunken ship be, the same set of pontoons can be used, and in all cases the raising ropes can be arranged truly vertically, so as to get a direct pull. And, moreover, with this direct pull the adjacent sides of the pontoons on the opposite side of the wreck do not press or bump against one another, the position of the ropes being so arranged that a sufficient distance between the pontoons is always maintained, which is very desirable.

In connection with these wells, and the lifting ropes, winches (as before described) are employed, by which the apparatus is capable of raising wrecks where practically no tide exists. The type of winch used for this purpose is one whereon the ends of the ropes are not carried and held on the winding barrel; but in each case the end is held on a separate reel or barrel, which moves with the winding barrel. This method of stowing and coiling the rope is employed, because only one set of coils of the rope can be coiled on the winding drum *c* of the winch (Figs. 11, 12, and 13), it being impossible to have the coils one upon another for the purpose such as described, where the weights to be raised are enormous, as coils one upon another will damage the rope, and might render it useless for further raising purposes after one use. In the case of the ship being, say, about 2,000 tons, and if the four pontoons shown be used, each winch and wire rope at each side will carry 100 tons.

When the ship is raised by the winches alone, they haul on the rope at both ends equally.

As regards the use of wire ropes, about ten or eleven inches in circumference, as at present made, is considered the maximum size that can be handled by men under such conditions as wreck raising; and therefore, practically the limit of weight which can be lifted is, in this sense, governed by this fact; nevertheless the weight which may be lifted will vary accordingly as more or less ropes are placed under a ship, and the pontoons are made larger or smaller.

When the ropes *c* (Figs. 2 and 3) do not pass directly through the centre of the wells *b* (Fig. 1), the water tanks of the pontoons on the side on which the lesser strain comes are partly filled with water to keep the pontoons on an even level.

When lifting ships which are not completely or deeply submerged by means of winches, the pontoons are placed as in Fig. 3, and the winches are placed on the off side of the pontoon, to counterbalance the weight which comes upon the near side, and, if this is not sufficient, the outside compartments of the pontoons are partially filled with water.

The bollards (see Figs. 4, 8, and 9) consist of large hollow steel cylinders *e* (4 ft. in diameter), angle plates e^1 riveted to the deck and to *e*, and brackets e^2 riveted to the deck and to *e* and e^1; and they are arranged in pairs as usual, one being on each side of the bulkheads *h*. At the edge of the pontoons over which the ropes would be passed, in cases as shown in Fig. 3, suitable rollers are provided to ease the movement of the rope over the bend.

The position of the winding barrel d^1 of the winches *d* (see winch in Fig. 4) is directly over the wells *b*; d^2 are bed-plates on the winches. The winches are moved as desired over the wells *b*, and suitable provision is made to secure them in any

required position, so that the lifting ropes from them are vertical and the adjacent sides of the pontoons will not touch in the lifting operations.

Regarding the pontoons, they have a longitudinal bulkhead *f* (Fig. 4) at either side and transverse bulkheads *h* running between the ends of the wells and vessel's sides, forming the side chambers into a number of compartments, and strength is given the vessel where the lifting ropes go over the side when lifting, as in Fig. 3. These compartments are filled and emptied as required for balancing and manipulating in the raising operations by pumps *k* (Fig. 4) through hollow box kelsons *i* (Fig. 7), running through the vessel, and valves *j* (Figs. 6, 7, and 10) in the kelson in each compartment. The pump discharge pipes k^2 and inlet pipes k^1 (Fig. 4) are both taken overboard on deck.

The chambers between the bulkheads *f* and wells *b* (Figs. 4 and 5), except those at the bow and stern, are used as engine, pump, and boiler-rooms, and men's quarters, or other purposes; while those at the ends can be filled or emptied to raise or lower either end of the vessel. The floor at the bow of the pontoons is curved up as shown, and the bow chambers are empty, and the stern ones partly filled with water or salvage gear when being towed.

Each valve *j* is opened and closed by a rotatable rod j^2 (Figs. 8 and 10), the actuating wheel of which is disposed within the hollow bollard *e* (Fig. 7). The valve seat j^1 (Fig. 10) is on the bottom of the kelson *i*, and a trunk j^4 (Fig. 10) extends from it to empty compartments as far as required. In the cover j^6 over the valves *j* is a stuffing box j^5. A valve *j* is provided at each end of the compartments to obtain full flow of water, and to pump the compartments dry if the pontoons are tilted.

The improvements covered under this invention are not restricted to the particular forms of the appliances illustrated, as these may be variously modified without departing from the chief characteristics of the inventions. For instance, a camel may consist of so many vessels, side by side, fastened together by suitable means, the wells *b* being formed by distance pieces between such vessels at their ends, which keep them separated and give the desired width of well. Or, in another modification, a number of wells in the form of tubular apertures through a pontoon, in rows transversely across the pontoons, may be used. These instances point out in a general way the manner in which appliances under this invention may be variously modified.

In conclusion, the proposed working of these appliances may be briefly described as follows:—The wire ropes are swept under the hull of the sunken vessel in the ordinary way, by small steamers, or by divers, the ends secured to the masts, if above water, or marked by buoys, until a sufficient number have been passed under the vessel.

The camels would then be towed out and arranged in pairs, to the number required, according to the length or weight of the vessel. The end of the wire hawser would be passed on the winches, which have been placed, according to the beam of the sunken vessel, either up through the transverse wells, if a direct vertical pull is necessary, or over the rollers at the sides if otherwise, and, having been hove tight, are then secured in the compressors and the spare wire coiled on the carriers. The winches are then set in motion (the engineer in charge, having his gauges before him, regulates the speed of each winch and the weight it carries) and slowly lift the sunken vessel from the bottom until the winding reels are full. The amount of rope capacity in the winch described is about thirteen fathoms, this being the limit necessary to correspond to the width of the wells, and to insure against any waste of force, owing to the ropes getting too much out of the perpendicular. In cases where the depths exceed thirteen fathoms, the camels with their burthen would be towed away to a place where the vessel could be safely beached, or if the distance to be towed presented serious difficulties, other ropes could be passed under the vessel and made fast to the bollards on the camels to take the weight, while the lifting ropes were regulated for a fresh heave, and so on until the sunken craft was hove close under, or up between the camels.

In finally concluding this paper, I respectfully suggest that the appliances—and principally I would accentuate the winch, with its gripping and fleeting powers—bring several possibilities into existence for their use besides those I have described. As for instance, in the unfortunate case of war arising, and any apprehension of an attempt of invasion of this country being made, there are many ports which could be readily protected from devastation by torpedo-boats, by sinking old vessels with the necessary wires passed under them, in the entrance of the ports, and when necessary these vessels could easily and quickly be lifted and taken away, as the only cause of delay in these operations would be the passing of the wires.

The President (the Right Hon. the Earl of Hopetoun): Gentlemen, as no one rises to make any remarks upon this paper, I think we ought to thank Mr. Kinghorn, who presented it, for the very interesting quarter of an hour we have had, and that we should also thank Captain Bell for the way in which he has read the paper.

COMPOUND MARINE BOILERS.

By Colonel N. Soliani, Director of Naval Construction, Royal Italian Navy; Member.

[Read at the Thirty-seventh Session of the Institute of Naval Architects, March 26, 1896; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

The steady advance of water-tube boilers in the field of steam navigation has aroused a natural reaction in favour of ordinary marine cylindrical boilers, which, according to many, although inferior in certain respects, possess features of great value for marine purposes, not yet fully secured in the new boilers. This view refers, however, to boilers for ships other than torpedo craft, which have requirements that only water-tube boilers can now fulfil. Within these limits the contention in favour of cylindrical boilers does not appear groundless.

In fact, the marine cylindrical boiler is not a new production of the inventive genius of man, but is the result of experience of two generations at sea. It is the last stage reached of development and improvement, under existing practical conditions, of an "organ" in the evolution of the entire "organism," "the steamship," to which it belongs. And, in such a long adaptation to surrounding conditions, the marine boiler, from the early types to the present one, has, in effect, developed features of real fitness for ocean navigation, and reached a state of perfection not easy to attain immediately with any new boiler.

The prominent features of the modern marine cylindrical boilers are well known, viz., efficiency, simplicity of parts, fewness of bolted joints, durability, easiness of inside inspection, fitness to available space on board ships, small liability to derangement, possible concentration of large power in few boilers, so reducing number and complication of pipes and fittings, steadiness of action by which water feed and steam pressure are under easy control, facility of repair of the heating tubes under steam, adaptability for temporary use of sea water for supplementary feed, &c.

Although some of the foregoing characteristics may be claimed also for water-tube boilers of various types, others of them are certainly special to the cylindrical boiler,

and it is to these important features that cylindrical boilers owe their success in the domain of ocean navigation and the present campaign in their favour.

In this respect it is worth notice that, if we except France, where water-tube boilers of the Belleville and a few other types are in general use, both for merchant and war ships, in England and other countries the Mercantile Marine has not yet shown any marked propensity to abandon its familiar and faithful servant; while the Navies, although now in full swing for the new boilers, began really to feel the want of a change, only when the cylindrical boilers "appeared" unsuitable to forced draught. I use on purpose the word "appeared," because I think it is not yet proved whether the proclaimed unsuitableness is unavoidably due to organic constitution of the boilers, or to the magnitude of the extra strain and suddenness with which it was applied before the boilers were given time to adapt themselves to the new demands made upon them.

In support of this view, I may mention the very good results obtained with the Serve tubes, and with the Howden and Brown systems of combustion, by which the steaming power of marine cylindrical boilers, per unit area of wetted heating surface, has been brought up to the limits which were lately deemed dangerous; but, apart from these arrangements, which, if efficient in increasing the specific power of the boilers, have certainly not improved them in respect of lightness and suitableness to rapid steaming—which are prominent features of the water-tube boilers—it may be asked: Have cylindrical boilers reached their last stage of development? Cannot such boilers compete much longer, or must they soon give way to the new comers?

Well, while it is pretty certain that, owing to certain important advantages which water-tube boilers offer, principally for Navy purposes, the difficulties which still beset their general adoption will be vigorously attacked and finally overcome, I think, from what has been said above, that cylindrical boilers not only have, as yet, a great power of endurance in the mercantile competition, but that there is still room on their side for further improvement, by which their vitality may be increased and the struggle prolonged, even for Navy purposes, with advantage to the great interests involved.

This new vitality may, I think, be conferred on cylindrical boilers by "compounding" them with water tubes in such a way as to make them partake, to a certain extent, of the good features of the water-tube boilers, without detracting much from their own valuable characteristics.

There are already in the market various compound boilers, viz., boilers having the heating surface made up both of water and fire tubes.

Such are the Roger boiler, the Barthlet boiler, the Anderson and Lyall boiler, &c.; but none of them, as far as I know, may be styled "a real compound marine

cylindrical boiler." Even the Anderson and Lyall boiler, although more akin to it, is altogether a different thing; it is a special boiler of itself, having features which belong to various types, resembling a locomotive boiler in its furnace, a marine boiler in its combustion chamber, and a stationary boiler in its barrel.

In saying so I do not wish to disparage these boilers, which, on the contrary, appear very good and efficient, but simply to show that they are not the kind of boiler I mean, viz., a marine cylindrical boiler compounded with water tubes to the extent that is necessary to give protection to the tubes and tube plates, and improve the boiler also in other respects (such as economy of weight, fitness to rapid changes of temperature, &c.), but without altering its main characters.

Such a result may, in my opinion, be achieved simply by doing away altogether with the water spaces around the ordinary combustion chambers and substituting for them water tubes, some of which would be properly arranged as a protecting screen in front of the tubes and tube plates.

My meaning will perhaps be clearer by reference to Figs. 1 and 2, Plate XLIII., in which the proposed alteration is sketched, as applied both to single and double ended cylindrical boilers.

Such boilers, if successful, would be lighter, simpler, less sensitive to difference of temperature and to rapid changes of fire; while the screen of water tubes in front of the tube plates would in them, as in the Anderson and Lyall boiler, protect, to a great extent, plates and tubes from damage under forced draught.

In other words, these boilers would fulfil most of the requirements of modern steaming at sea, and exert, if adopted, a useful function in the present period of transition, which, by them, would become longer and smoother.

The benefit would be mainly felt by the Mercantile Marine, on account of the larger interests involved, and because of its requirements, to which the ordinary marine boilers appear, on the whole, so well suited.

Another advantage of the arrangement I propose would be the facility of admitting air under the back end of the fire-grate, in a proper measure, to improve the efficiency of combustion, through a regulating door fitted under the bridge and underneath the casing of water-tubes forming the combustion chambers.

In marine engineering I am only a *dilettante*, therefore in what I have had the honour to say, my aim has been simply to raise a question which seems important, and to merit discussion by the experienced members of the Institution. My suggestions may be briefly summarised as follows, with a view to meet discussion :—

(1) For swift vessels, of small dimensions, designed for the use of torpedoes or special services, water-tube boilers are a necessity.

(2) For certain classes of warships of larger size, water-tube boilers are distinctly advantageous.

(3) For mercantile purposes and many classes of warships, the water-tube boilers are not yet perfectly suitable, and the cylindrical type of marine boiler is still to be preferred and its continued employment is probable for some considerable time.

(4) There is a possibility of retaining the most valuable characteristics of the cylindrical type, while securing increased efficiency and fitness to meet the exigencies of modern steaming, by means of arrangements of water-tubes somewhat of the character illustrated by Figs. 1, 2, and 3, Plate XLIV.

WATER-TUBE BOILERS.

By J. Watt, Esq., Associate.

[Read at the Thirty-seventh Session of the Institution of Naval Architects, March 26, 1896; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

Some years ago the writer had the honour of reading a paper on the subject of water-tube boilers before the Liverpool Polytechnic Society, and, after enumerating the points which constituted a good water-tube boiler, deduced therefrom the following rules or laws, which should be observed in designing a trustworthy steam generator. They were as follow :—

(1) "The tubes should be arranged in a position to absorb the greatest amount of heat, by causing the flame to travel in an upward direction at right angles to their axis.

(2) "The tubes should be in a horizontal or inclined position, as the most efficient to emit heat.

(3) "The steam generated should have free and unobstructed escape to the steam receiver.

(4) "The circulation or supply of water to the tubes must be copious to prevent overheating.

"These are the theoretical, and form the essential, conditions of an efficient water-tube steam boiler.

"But, in addition to these, there is another not the less important which concerns the practical part or life of a boiler, viz., the facilities for inspection, cleaning, and repairing."

It is twenty-two years since the above was written, and, although old, it is quite as applicable to-day as then; and, as far as the writer's experience goes, quite borne out by practice. There is, perhaps, no water-tube boiler made that will fully come up to all the requirements here laid down, but the nearer we can approach this standard, the more perfect and successful will be the boiler; and by applying this standard to any existing boiler, we are enabled to point out, not only its merits, but also its defects.

It is not the writer's intention of going over the whole range of this subject of water-tube boilers, but to lay before you the result of a few experiments, which may elucidate and explain some of the many mysterious circumstances connected with this complex subject.

A water-tube boiler may be defined simply as an assemblage of tubes filled with water and placed over a fire. The ends of the tubes are fixed to two receivers, which combine the whole together. If the receivers be cylindrical where the tubes fit, then the tubes are more or less bent to suit; if flat, the tubes are generally straight. The advocates of bent tubes claim the bending as important in taking up, or accommodating themselves to, the expansion of the boiler when under steam. On the other hand, those who advocate the straight tubes find no difficulty arising from this point. Straight tubes offer the best advantages in respect of inspection, cleaning, and renewals.

The experiments were made with a small model boiler (see Figs. 1 and 2, Plate XLV.) containing thirty-nine straight tubes, each $\frac{3}{8}$ in. diameter by 9 in. long, containing 2·9 sq. ft. of heating surface. The receivers to which the tubes were attached were flat, the end plates were of glass, so that the tubes could be seen right through, and the action going on inside could be distinctly observed. A steam receiver was also placed on the top, connecting the other two receivers. Heat was supplied by two Bunsen burners, consisting of two tubes with cross slots, the heating taking place being very much similar to that of an ordinary firegrate furnace. The model was so constructed that it could be used or tried in a great number of different positions.

The object of the first series of experiments was made with a view of finding out the relative value of heating surface when the tubes were angled from a horizontal position, gradually, to that of a vertical one, or through an angle of 90°. The experiments were conducted at atmospheric pressure, and commenced by first raising a given weight of water to the boiling-point, and then ascertaining the amount evaporated after an interval of fifteen minutes.

After a few preliminary trials it was found that when the boiler was angled about 10° from the horizontal the evaporation was highest, viz., $8\frac{1}{2}$ oz.; when the angle was increased to 15°, the evaporation was $8\frac{1}{4}$ oz.; 30°, $7\frac{1}{2}$ oz.; 45°, $6\frac{1}{2}$ oz.; 60°, $5\frac{3}{4}$ oz.; 75°, $5\frac{1}{2}$ oz.; and 90°, 5 oz. Again, on reducing the angle to 5°, the evaporation was $8\frac{1}{4}$ oz., and when level $7\frac{1}{2}$ oz. It may be here stated that, owing to the pressure of gas varying a little, very seldom the same results could exactly be arrived at; but by making several trials the above is a fair average. This is graphically represented in Fig. 3, Plate XLV. (top curve). The vertical ordinates represent the percentage of evaporation at the various angles at which the boiler was tried, beginning at the horizontal position and gradually rising to the vertical position. It was found when the

boiler was angled 10°, it gave the best result; therefore 10° represents the maximum evaporation, or 100 per cent.

In looking at this diagram, we find that in any water-tube boiler whose tubes are inclined, say, 10°, by merely increasing the angle to 30°, the amount of water evaporated is reduced from 100 to 85, or 15 per cent. less. If the angle be increased to 60°, the decrease will be 33 per cent. And at 90°, or the tubes vertical, the reduction is a little over 40 per cent. This compares very favourably with the old-fashioned rule employed in the ordinary steam boiler, of allowing two square feet o vertical heating surface to be of equal value to each one of horizontal.

These experiments were conducted with the tubes placed in horizontal rows, so as to allow the products of combustion to travel in a zig-zag direction to the funnel. The next series were taken with the boiler turned on its side, so as to form the tubes into vertical rows, and giving the products of combustion a more direct course to the funnel (see Fig. 2A, Plate XLV.). The result is shown by the lower curve on Fig. 3. The highest percentage was 82 per cent. at 10°, and 53 per cent. at 90°, the best result showing a difference of 18 per cent. in favour of the former arrangement of tubes.

Instructive as these tests may be, the next series will show still more striking results. Their object is to arrive at the duty performed by various tubes or rows of tubes, and more especially those nearest to the source of heat. If we take another boiler—or, rather, a part of a boiler representing that row of tubes which is nearest to the fire—and place the two together, as represented in Fig. 4, Plate XLVI., we have the means of arriving at the evaporation of each boiler separately. This small boiler consists of six tubes only, having a heating surface of ·44 sq. ft., compared with the larger one of 2·9 sq. ft., or a combined heating surface of 3·34 sq. ft.

The results of this arrangement are represented on diagram Fig. 5, Plate XLVI. The upper curve shows the combined evaporation of both boilers, and, although there is an augmented heating surface of about 15 per cent., yet there is very little difference in the amount evaporated. The lower curve shows the evaporation of the original or larger boiler, and we now see that at its best it is reduced from 100 per cent. to 40 per cent. at 10°, and from 60 per cent. to 17 per cent. at 90°. On the other hand, the small boiler is represented by the middle curve, and its evaporation at its best is 60 per cent. at 10°, and 45 per cent. at 90°. The above results may be stated in other words, viz.:—That practically 60 per cent. of all the steam generated in any water-tube boiler with tubes at any angle is generated in the first or nearest row of tubes to the fire. The remaining 40 per cent. is left for the larger portion of the boiler to accomplish.

By reversing the positions of the two boilers—by placing the smaller on the top of the larger one—we can arrive at the evaporation of the top row; but this was found to

be so small as not to be worth taking notice of. The writer had not the means of testing the intermediate rows ; but the following table will not be very far off :—

1st	row	nearest	to the	fire	evaporated	60·0	per cent. of the total	evaporation.
2nd	,,	,,	,,	,,	24·0	,,	,,	,,
3rd	,,	,,	,,	,,	9·5	,,	,,	,,
4th	,,	,,	,,	,,	3·5	,,	,,	,
5th	,,	,,	,,	,,	1·5	,,	,,	,,
6th	,,	,,	,,	,,	1·0	,,	,,	,,
7th	,,	,,	,,	,,	0·5	,,	,,	,,
					100·0			

The importance of the above cannot be overlooked. Either the first row is doing too much or the back row too little ; and the conclusion arrived at is that, practically, the first row is receiving the whole wear and tear of the boiler, and is therefore more liable to damage and renewals. This has proved itself in the case of copper tubes, which, although a better conductor of heat than either iron or steel, yet were unable to stand the severe work they had to perform. The danger from overheating and rupture is not only very unpleasant from a stokehold point of view, but the giving way at some critical moment, demands our most important consideration ; in short, it is the vital part of the water-tube boiler.

Seeing this difficulty some time ago, the writer devised some means by which the first row was relieved of this heavy duty, and more laid on those immediately behind. This is accomplished by substituting tubes of much larger diameter nearest to the fire than those which are more remote. The larger tubes contain more water, and present less heating surface, for the space occupied, than those of smaller diameter. The result is that the evaporation is less with the larger tubes but greater with the smaller. Fig. 6, Plate XLVI., represents the arrangement. For the six $\frac{3}{8}$ in. tubes we now adopt three $\frac{3}{4}$ in. tubes in their place. The weight of water in the three tubes is double that in the six smaller ones, while the heating surface remains the same. The diagram representing the results of the trials is shown on Fig. 7, Plate XLVI. The top curve, as before, representing the results of the two boilers. Practically there is very little difference compared with the similar top curves of Figs. 3 and 5 ; if anything, it is slightly in favour of Fig. 7. But when we come to compare the two lower curves with the similar curves in Fig. 5, we find that they have almost changed places. Taking the top or larger boiler, the evaporation at 10° is nearly 60 per cent. of the total as compared with a little over 40 per cent. shown on the former trial. The curve dropping down at 90° to 27 per cent. against 17 per cent. Taking the lower boiler, representing the three large tubes, the evaporation is reduced from 60 per cent. to a little over 40 per cent. at 10° with the larger tubes, terminating at 38 per cent. at 90°. It will be observed that the two curves cross each other when the boiler is at an angle

of about 55°, showing that the evaporation at this angle is about equal in each boiler. From this point on to 90° the smaller boiler evaporates more than the larger; but, as the angle decreases below 55°, the larger boiler evaporates more than the smaller. We here see that the evaporation in the first row of tubes is very much reduced, there is less liability to overheating, and accidents are reduced to a minimum.

The quantity of water evaporated by the first row of small tubes was at the rate of 5 lbs. per square foot of heating surface per hour, and the velocity at the end of the tubes, about 3·8 ft. per second. The tubes were full of semi-steam and water, so that no light could be seen at the other end; evidently these tubes were evaporating their maximum quantity with efficiency.

On the other hand, with the row of large bottom tubes, the rate of evaporation was about 3·5 lbs. per square foot heating surface, and the velocity at the tube ends (steam only) about 2·9 ft. per second. Up to an angle of about 60° a light could be distinctly seen through these tubes, the steam occupying about one-third of the area on the top side, the water underneath presenting a clear solid mass. Above 60° elevation the water and steam became more or less mixed up, so that a light could not be seen at the other end. From the apparently easy manner in which these tubes were doing their work, it was evident the maximum amount of evaporation had not been reached. There was a large reserve of solid water in the tube, and the steam appeared to pass freely away without taking any water along with it. Indeed, there could not be a strong water current, for on blocking up the bottom end of one tube to the extent of reducing its area to one-fourth, there appeared to be no different result.

It must be remembered that the above trials were made at a pressure of one atmosphere where the relative volumes of steam and water are as 1,640 to 1. For higher pressures a corresponding rate of combustion may be adopted.

The most vital parts in any water-tube boiler, and the most easily damaged by overheating, are those tubes in close proximity to the fire. To overcome this difficulty two courses are open: (*a*) by adopting small tubes and providing for a vigorous circulation; (*b*) by adopting larger tubes and a less active circulation. Adopting the former, there is a limit both in respect to the speed of the current and the quantity of steam in contact with the heating surfaces. According to Mr. Thornycroft's experiments, at a pressure of three atmospheres, the relative volume of steam and water passing through a number of $1\frac{1}{8}$ in. tubes was about 5·4 to 1, and at 12 atmospheres this would equal $1\frac{1}{2}$ to 1, or three volumes of steam, at an average, in each tube, to two of water. A condition of things which presents to us two evils: one is the danger arising from the tube becoming much hotter than the temperature due to the pressure. As an instance of this, there is the failure of copper tubes in water-tube boilers to stand this excessive heat. The second evil is the slow corrosion taking place, owing to part of the

steam in contact with the tube becoming decomposed at a high temperature, forming oxide of iron and hydrogen gas. Some years ago apparatus for superheating steam were placed in uptakes; but even at this low temperature their life was three or four years at the most.

By the improved arrangement of larger tubes to face the first and direct action of the fire, a larger body of more solid water is in actual contact with the heating surfaces. The liability to damage by over-heating is reduced to a minimum; the duty of the various tubes more evenly distributed, and the steam generated more freely disengaged.

In conclusion, there is one point which, during the time these experiments were being made, confirmed the writer's views more strongly of a grave defect in Belleville water-tube boilers for marine purposes, and, as this boiler is now being freely adopted by our Admiralty, his humble protest must be taken from a tax-payer's point of view.

Those who are responsible for the position and arrangement of this boiler on board of a sea-going vessel have evidently not given the subject of an unsteady platform any consideration. Numerous tubes have given way at sea; not that it is the only boiler which suffers from defective tubes; but in all probability these same tubes would not have given way had the boiler not been tossed about in a sea way. In many instances these tubes have been replaced by thicker ones, and in some cases by Serve tubes, with little better results. Still the true cause of their failure is not discovered, therefore no effectual remedy applied, and thus the error is repeated.

The arrangement of all water-tube boilers, with horizontal or slightly inclined tubes on board ship, should be parallel with the line of keel. But it appears to be the rule, so far as the boiler in question is concerned, to place the same across the ship. Now, the inclination or angle of the Belleville boiler tubes is about 2° or 3° from the horizontal, and as 10°, say, is not an uncommon angle for a ship to roll at sea, it follows that the tubes will become depressed or angle reversed to the extent of 7° or 8°.

A ship to roll from eight to ten rolls per minute is not uncommon, and therefore six or eight seconds would be the duration of one roll.

Now, imagine the ship rolling, a heavy fire on the grate, and in this time these lower tubes generate, as we have seen, such a large volume of steam as would immediately reverse the circulating current, fill the upper ends and be here imprisoned, only to be relieved by the next roll. The greater portion of the steam will now be transferred to the other end, to be again re-imprisoned, and so on till the ship gets into less turbulent waters.

With reference to what the continued effect on these semi-dry tubes would be in a sea-way, or in the event of he ship having a list, the result is left for your better and impartial judgment.

CIRCULATION IN WATER-TUBE BOILERS.

By Professor W. H. Watkinson, Associate.

[Read at the Thirty-seventh Session of the Institution of Naval Architects, March 26, 1896; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

The main object of this paper is to draw attention to a series of models, which will be shown in action at the meeting, and which I have had constructed in order to show the nature of the circulation in the various types of water-tube boilers. The tubes in these models are of glass, ranging in internal diameter from $\frac{3}{8}$ in. to $1\frac{1}{2}$ in., and the drums are provided with glass ends, so that the whole of the action in the boilers can be observed.

As there has been a great deal of discussion, and as inaccurate views are still prevalent regarding the causes of circulation in water-tube boilers, it will be well, before describing the action in the various models, to summarise the author's conclusions regarding this matter.

Causes of Circulation.

"The causes of circulation in water-tube boilers are:—

(1) The difference in density of the water due to difference in temperature when the fires are first lighted. This circulation is very sluggish.

(2) When the water is all at approximately the same temperature, and steam is being generated, but not with sufficient rapidity to cause a break in the continuity of the water, a much more vigorous, but mainly local, circulation is set up by the entraining action of the bubbles of steam rising through the water.

(3) When steam is generated with such rapidity, that in some part of the circuit there is steam or foam only present, a very rapid circulation takes place, due to the difference in density between this steam, or foam, and the continuous water in the downcomers, internal or external." *

* From a paper by the author, Inst. Engineers and Shipbuilders in Scotland, January, 1895.

These conditions are illustrated by the annexed diagrams. In Fig. 1, Plate XLVII., steam is not being generated rapidly enough to completely fill any portion of the tube A with either steam or foam, and the continuity of the water in A being unbroken, the only cause of circulation, assuming the water to be all at the same temperature, is the entraining action of the bubbles rising through the water.

By many the circulation, in this case, is said to be due to the difference between the density of the column of water in B, and the average density of the steam and water in A. That this is not so is shown by the experiment illustrated in Fig. 2, Plate XLVII., in which air is sent into the inner tube from a horizontal nozzle at C. When the top of the inner tube is above the water-level the rise of level in the inner tube is very small, and when the conditions are as shown the circulation is comparatively sluggish. If the nozzle C, however, be turned upwards a much better circulation is induced, but the action in this case is not analogous to that in a boiler.

Another way of regarding the matter is indicated in Fig. 3, Plate XLVII., where a series of beads is shown attached to a fine wire.

When the beads are moved either upwards or downwards a circulation is set up due to their entraining action, exactly as in Fig. 1.

The circulation, therefore, under the conditions shown in Fig. 1 is due solely to entraining action, and not to difference in density of the substance in the two legs. It is due really to the difference in density between the steam and water in the same leg, which sets up a relative flow of the two, and the entraining action of the rising bubbles causes the circulation round the circuit, as well as the local currents which are at the same time induced.

In Fig. 4, Plate XLVII., steam is being generated more rapidly, and portions of the tube are filled with steam to the complete exclusion of water from these portions.

In this case a rapid circulation takes place on account of the average density of the substance in A being less than that in B. This kind of circulation is by far the most thorough, as none of it is merely local.

When working at atmospheric pressure,at rates exceeding about 2 lbs. of steam per square foot of heating surface per hour, and with tubes 1¼ in. in diameter, the bubbles do not fill up the whole diameter of the tube, as shown in Fig. 4, but the upper part of the tube becomes filled with foam to the complete exclusion of continuous water, as shown in Figs. 7, 8, and 10, Plate XLVIII.

The circulation in this case is, of course, due to the difference in density between the foam in tube A, and the corresponding column of water in tube B, Fig. 10.

The circulation in this case is also vigorous, but, as a considerable amount of water falls down from the foam, it is more local, and not as thorough as in the last case.

Description of Models.

Model of Belleville Boiler (Fig. 5, Plate XLVIII.).

This consists of one element, containing 20 tubes of $\frac{15}{16}$ in. internal diameter joined in series.

The distance between the centres of the end boxes is 2 ft. 3 in., and the inclination of the tubes is 4 per cent., as in actual boilers of this type.

The action of the automatic non-return valve at A is very clearly shown.

The normal level of the water is about that of the middle tube, but in starting the model, in order to prevent overheating of the upper tubes, it is necessary to have water in all the tubes.

The action in the Belleville boiler is so different from that in any other boiler that it may be well to explain it somewhat fully. As is well known, this boiler consists of a number of elements connected in parallel between the feed distributing box (as I prefer to call it) and the steam drum. The total length of tube in each element is roughly 150 ft., and, as the inclination is only 4 per cent., the upper end of this 150 ft. of tubing is only 6 ft. above that of the lower end, and the discharge into the drum takes place at about $1\frac{1}{2}$ ft. above this.

If each element consisted of one straight tube 150 ft. long instead of twenty tubes connected by end boxes, as in the actual boiler, the circulation would be of the same nature as that in other water-tube boilers, and a circulating force of, say, 1 lb. per square inch (assuming the head effective for circulation to be 2 ft.) might be great enough to push the water through the tubes, in spite of their great length. Owing, however, to the abrupt changes in the direction of flow of the water which take place at each junction box, the total resistance to the flow is too great to allow sufficient circulation with this circulating force.

To get over this difficulty the orifices through which the water flows from the feed distributing box to the elements are very contracted, and at the bottom of each of the two downcomers is an automatic non-return valve.

With these arrangements the action of the boiler is similar to that in the old-fashioned Savery steam-pump; the water is forced into the elements intermittently by the available head of about 2 ft. instead of by the atmosphere, as in Savery's pump,

the non-return valve and the contracted orifices serve as the suction valve, the steam is generated in the tubes themselves instead of in a separate boiler, and the necessity of a delivery valve is got rid of by discharging into the steam drum above the water level.

The action, therefore, is intermittent, and some water is driven backwards through the contracted orifices during the time plugs of water and steam are being pushed forward into the steam drum. The non-return valves prevent water being driven back through the downcomers into the steam drum.

When warming up the action is intermittent, as in all cases where the discharge takes place above the water-level, but in this case there is a violent water-hammer action, owing to the form of the end boxes, and to steam being generated in several of the tubes at once. Steam generated in the lowest tube pushes the water up into the upper tubes; the steam formed in the upper tubes tries to push this water back again at the same time that it pushes the water in front of it forward into the upper drum; and on this account when first raising steam the shocks are often very violent.

When properly in action the circulation is very vigorous and thorough, the alternating plugs of water and steam racing each other through the tubes of the element at a very high speed. The amount of water in the tubes is, however, very small, excepting in the lowest tube of each element, which contains much more than any of the others. The circulation in the lowest tube of the element is least thorough, and is partly alternating.

Model of Yarrow Boiler (Fig. 6, Plate XLVIII.).

It will be observed that one half of this boiler is arranged with the tubes discharging below the water-level, as in actual boilers of this type, and the other half with tubes discharging above the water-level. An external downcomer is provided for each half, and a plug is provided so that the downcomer for the drowned tubes may be closed. Either half of the boiler may be used separately.

(1) Action with the submerged tubes and with the downcomer shut off.

As soon as the fires are lighted circulation commences, and when boiling first begins, plugs of steam and water are periodically projected into the upper drum, causing a considerable disturbance of the water-level there. When the boiler is working at a high rate of evaporation, the discharge from most of the tubes is practically continuous, and the disturbance of the water-level not so violent. Some of the tubes, which are not as highly heated as the rest, act as downcomers, while in some others the flow is alternating in direction. When the external downcomer is

used, the circulation is not as rapid, because more of the tubes act as upcomers, and therefore the average length of the foam column in the upcomers is less; there is less alternating flow, but some of the tubes still act as downcomers.

When the other half of the boiler is used, in which the tubes discharge above the water-level, there is, of course, no circulation until boiling begins, but on this account steam begins to be formed in the tubes nearest the fire almost immediately after the heat is applied.

This steam projects the water in the upper part of the tubes into the steam drum, cool water flowing from the drum through the downcomer to take the place of the water thus discharged. The action during warming up, then, is of an intermittent character, but, as the average temperature of the water in the whole boiler is increased, the intervals between the discharges become less and less, and when the boiler is working at a high rate of evaporation the action is quite continuous, if the area of the downcomers is sufficiently great. Each half of this model consists of sixteen tubes, in four rows, each tube being $\frac{7}{16}$ in. internal diameter, and the tubes in the different rows are opposite the spaces in the other rows.

The internal diameter of the downcomers is $\frac{15}{16}$ in., therefore the area of each downcomer is equal to $\frac{1}{3 \cdot 4}$ of the area of all the tubes served by it.

Model of Thornycroft Boiler (Fig. 7, Plate XLVIII.).

This consists of twelve tubes, $\frac{7}{16}$ in. internal diameter, with a downcomer $1\frac{1}{2}$ in. diameter.

The area of the downcomer is therefore approximately equal to the area of the tubes served by it.

When heat is applied to this boiler, an intermittent discharge of plugs of water is almost immediately set up, due to formation of steam in the tubes, although the water in the upper and lower drums is practically cold. This action is obviously of great service in preventing overheating of the upper portions of the tubes which, before this action commences, do not contain water. In actual boilers of the *Daring* type, with internal heated downcomers, circulation of water between the drums will be started through the downcomers as soon as the fires are lighted. As before remarked, at high rates of evaporation, even with tubes below half an inch in diameter, the water and steam do not follow each other in plugs; the upper halves of the tubes are more or less filled with coarse foam, to the complete exclusion of continuous water.

Under these conditions the circulation is wonderfully active, and the water part of the foam is projected in a continuous stream right across the steam drum, as shown, the steam being given off freely, and the water-level is only very slightly disturbed.

Model of Babcock Boiler (Fig. 8, Plate XLVIII.).

This model consists of three tubes, each $1\frac{7}{16}$ in. internal diameter, and the distance between the centres of the headers is 33 in. The tubes are inclined at 15° to the horizontal.

The circulation in this case is due partly to the entraining action of the bubbles moving through the inclined tubes, partly to the foam filling the upper ends of these tubes, but mainly to the column of foam in the front header. When the level of the water before starting is below that of the bottom of the steam drum, a much smaller drum may be used, without priming taking place, than when the water-level is above.

The circulation in the upper tubes, with this type of boiler, is better when the water-level is in the steam drum than when it is below the steam drum.

When the water-level before starting is below the bottom of the steam drum (see Fig. 8, line A B), as soon as the boiler has got into full action a large amount of water is carried up into the drum along with the steam, and there is a continuous and very rapid flow of water along the bottom of the drum, as shown.

Model of Niclausse Boiler (Fig. 9, Plate XLVIII.).

In this model there are five tubes, each 1 inch internal diameter and 18 inches long. The internal tube is $\frac{3}{8}$ in. internal diameter, and the inclination is 15°. The action is practically the same as in the Babcock boiler.

Effect of Inclination of Tubes on Velocity of Circulation.

When each tube draws its supply of water directly from a water drum, and discharges it directly into a steam drum, the greater the inclination of the tubes to the horizontal the better the circulation. If the tubes draw their supply from, and discharge their steam into, headers, the inclination of the tubes does not greatly affect the circulation, providing it does not fall below about 15°, and providing the currents from the different tubes do not interfere with each other. This is because the circulation in boilers of this type is mainly due to the low density of the foam in the upper part of the front headers. When the inclination is much below 15°, no matter whether the supply of water to the tubes is from a back header or is by means of internal tubes, the circulation is largely local, and the amount of water in the tubes is very small.

When the tubes are only slightly inclined to the horizontal, the only safe way of preventing the water being driven out of them is to use a non-return valve, or a very contracted orifice at the lower end of each tube: with a non-return valve the tubes may be quite horizontal.

Relative Advantages of Above and Below Water Delivery of Steam.

When the discharge takes place just at the water-level, it seems evident that the velocity of circulation must be a maximum, because the head of water effective for circulation is the same, whether the discharge takes place at or below the water-level. In the latter case, however, part of the energy due to this head is expended in giving motion to a considerable body of water in the drum, and the velocity of circulation through the tubes must necessarily be less than when the discharge takes place at the water-level. If tubes are carried much above the water-level the circulation is, of course, reduced in these tubes.

When the discharge takes place above the water-level the area of the downcomer is constant under all conditions, but when the discharge is below, this area varies even when external downcomers are used, because, the number of tubes acting as downcomers varies with the rate at which steam is being generated. The greater the rate of evaporation the smaller the total area of the downcomers.

When the discharge takes place above the water-level a much smaller drum may be used for a boiler of a given power, and priming is less likely to take place, because the water-level in the drum is only very slightly disturbed, whereas when the discharge takes place below the water-level the disturbance is considerable.

Should straight or curved tubes be used?

From what has been said in connection with the action of the boilers when the fires are first lighted, it will be evident that when the discharge is above the water-level, some parts of the boiler may be at a very much higher temperature than other parts. From this it seems to follow that, when the discharge is above the water-level, provision must be made for free expansion of the tubes, either by bending them, or by leaving the ends free, as in the boilers of Belleville and Niclausse. When the discharge is below the water-level, the temperature throughout will never differ much from that of the water, providing the circulation is good, and in this case straight tubes may be used without difficulty.

The author has found, by calculation, that when evaporating at the rate of 20 lbs. of steam per square foot of heating surface, the difference in temperature between the inside and outside of the tube is only 2·6° Fahr. for each $\frac{1}{16}$th of an inch in thickness of the tube in the case of steel. The temperature of the metal will, of course, be a few degrees above that of the water, but the more rapid the circulation the less the difference in temperature between the water and the tube. When working at the above rate, if the water be entirely driven from the heating surface for one second, and the thickness of the tube is $\frac{1}{8}$th of an inch, the rise in temperature in that time will be less than 10° Fahr.

Assuming a difference of even 100° Fahr. between the temperature of some of the tubes and that of others, the difference in length in the case of a tube 5 ft. long due to this difference in temperature would be only ·04 of an inch. If the external diameter of the tube be $1\frac{1}{8}$ in. and its thickness $\frac{1}{8}$th of an inch, the force necessary to prevent any increase in length due to this increase in temperature is 3·15 tons. This corresponds to about 8 tons per square inch of the metal, which is sufficiently below the limit of elasticity of mild steel to prevent injury to the boiler, even should the above unlikely difference of temperature ever exist between the different tubes of the boiler.

By using bent tubes it is possible to obtain a much larger amount of heating surface for a given number of joints, and a given amount of space occupied by the boiler.

Relative Advantages of Heated and Non-Heated Downcomers.

With a given rate of evaporation from a given amount of heating surface, the greatest velocity of circulation will be obtained when all the heat is supplied to the upcomers; but if additional heat be applied to the downcomers, the velocity of circulation will be increased, so long as the amount of heat supplied to the downcomers is insufficient to generate steam with sufficient rapidity to nearly exclude continuous water at some part of the downcomers.

In all these models the velocity of circulation is increased by applying a moderate amount of heat to the downcomers.

For this reason it is probable that the circulation in the Thornycroft boilers is more vigorous in those of the *Daring* type than in those of the *Speedy* type.

In boilers where the discharge takes place below the water-level, as in the Yarrow, Normand, Babcock, D'Allest, &c., even when special external downcomers are provided some of the tubes most remote from the fire act as downcomers.

In connection with downcomers it is important to note that the entrance to the downcomers ought to be removed as far as possible below the surface of the water in the drum, otherwise the reduction in pressure just inside the upper end of the downcomer may be sufficient to cause steam to be generated in it at that part. The steam thus formed would, of course, be condensed on its way down by the increased pressure. This action is indicated in Fig. 11, Plate XLVII. In connection with internal heated downcomers, insufficient attention has, I believe, been paid to the advantages of a few tubes of larger diameter being placed in the midst of tubes of smaller diameter.

Determination of $\frac{\text{Weight of Circulating Water}}{\text{Weight of Feed Water}}$.

When considering the best method to be adopted in order to determine this ratio, the author first thought that the best arrangement would be by means of a circular thin-lipped orifice, of known dimensions, placed near the top of the downcomers, but it soon became evident that, although this method might be adopted for cases where the discharge takes place above the water-level, it could not be used in cases where the discharge is below the water-level, because in these cases some of the tubes act as downcomers, no matter how large the external downcomer may be.

In order to get over this difficulty, the author used the model illustrated in Fig. 10, Plate XLVIII., which consists of only one upcomer and one downcomer. By means of the loose glass tube shown attached to the brass rod in the steam-drum, the discharge may be made to take place above the water-level.

After trying various methods for measuring the circulation it was found that the simple water column pressure gauge was the most convenient, and of sufficient accuracy for present purposes.

In Fig. 10 this is shown attached to the top of the lower drum, another column being attached to the bottom of the steam drum as shown. The head available for circulation is the difference in the heights of these two columns, and the velocity of the water in the downcomers is proportional to the square root of this difference of levels.

In connection with this, it is important to remember that this difference of level may be increased, either by an increase in the velocity of circulation, or by an increase in the resistance to the flow of the water from the upper to the lower drum.

The following results were obtained with this apparatus when working at atmospheric pressure and evaporating 13 lbs. of water per hour. The evaporation per hour per square foot of heating surface actually subjected to flame being 10·8 lbs. :—

Area of Downcomer.	Area of Upcomer. / Area of Downcomer.	Depression of Water Column		Weight of Circulating Water / Weight of Feed Water		Remarks.
		Discharge above.	Discharge below.	Discharge above.	Discharge below.	
Sq. in.		In.	In.	Lbs.	Lbs.	
·087	11	21	18	40	37	
·359	2·6	$8\frac{1}{4}$	$7\frac{1}{4}$	147	138	
·994	0.95	$3\frac{1}{4}$	$3\frac{1}{4}$	242	242	The difference between these two readings was so small that it could not be read.

By means of the glass-tube extension to the upcomer, it was possible to take the readings of the columns when discharging above, and when discharging below the water-level, immediately after one another.

To determine the weight of circulating water in each case, separate tests were made for each size of downcomer with the upcomer disconnected, and the outlet from the bottom drum contracted to give a suitable difference of level between the columns.

Water at about 200° Fahr. was then syphoned into the upper drum, and the weight of water flowing down the downcomer per minute, and the difference of level of the column being obtained, it was possible to determine, with considerable accuracy, the weight of circulating water under the actual conditions of working as given in the above table.

At the summer meeting of this Institution in July, 1894, Mr. Thornycroft read a most valuable paper, giving the results of some tests which he had made with model boilers, in one of which the discharge took place above the water-level and in the other it took place below the water-level. The circulation in both cases was measured by a water column, as in my own experiments. He found that the depression of this column was much greater when discharging below the water-level than when discharging above, and from this he concluded that the circulation was less in the former case than in the latter. M. Normand, in the important paper which he read before this Institution at the meeting in June, 1895, referred to Mr. Thornycroft's paper, and stated that he drew precisely opposite conclusions from the results of Mr. Thornycroft's experiments.

If the total area of the downcomers had remained constant M. Normand's conclusions would have been correct, but, as we have seen, in all cases where the discharge takes place below the water-level some of the tubes act as downcomers, and therefore the total area of the downcomers is variable. The height of the gauge column is the head of water equivalent to the water and foam in the upcomers, that is, the difference in the levels of the two gauge columns is directly proportional to the average length of the foam columns in the upcomers, and, therefore, the greater the depression of the gauge column the greater the average amount of steam in those tubes which act as upcomers. For a given rate of working it is obvious that if some of the tubes act as downcomers the rest must contain more steam than if all were acting as upcomers, and, unfortunately, these are the tubes nearest the fire. We have seen from the experiments with the single upcomer and downcomer that the circulation is better when the discharge is above the water-level, and now we have seen that, even when outside downcomers are used, the tubes contain more steam when the discharge is below than when above. The conclusion, therefore, seems to be that, those boilers in which the discharge takes place

above the water-level, other conditions being the same in both cases, will be able to stand heavier forcing than those in which the discharge is below the water level.

Advantages of Rapid Circulation.

(1) The more rapid the circulation, at a given rate of working, the greater the proportion of water present in the tubes, and, therefore, the smaller the difference between the temperature of the tube and that of saturated steam at the given pressure, and the less the liability to overheating.

(2) The more rapid the circulation, the less the oxidation of the tubes due to air liberated from the water.

(3) The more rapid the circulation, the less the incrustation, because less of the steam will be generated at the tube surface, and more of it will be generated by reduction of pressure in the upper part of the tubes, within the mass of water in the tubes.

The rapid motion of the water also tends to wash away solid matter as it is liberated from solution or suspension in the water.

When I commenced to write this paper my intention was merely to describe the action in the various models shown, but, as practically the whole of the problems connected with the design of water-tube boilers depend on the nature and amount of the circulation under various conditions, I was gradually led into a discussion of some of the most important problems which are affected by the circulation.

DISCUSSION ON THE THREE PRECEDING PAPERS.

Mr. A. J. Durston, C.B. (Member of Council): My Lord, for the first paper read this evening I am sure we all heartily appreciate the spirit which has animated Colonel Soliani in coming over here and expressing his views in such an able and clear manner, as he has done, on this interesting question, and putting before us for discussion the issues he has mentioned. One may feel confident he will receive the heartiest commendation of the meeting. One also feels gratified to see at this meeting so many able representatives of our nearest comrades across the silver streak, whose experience in the practical application of water-tube boilers has been the greatest, and whose opinions will be of the utmost value to this meeting and to the country generally. To the able author of the paper on circulation, and for the exhibition of his very instructive models, our great thanks are owing, and we duly appreciate the paper, also, of one of the early workers in water-tube boilers in this country, Mr. Watt. As many members will wish to speak on these papers I will make my remarks as short as possible. Referring to Mr. Watt's paper, it appears very probable that by arranging the tubes as

he proposes in water-tube boilers, viz., with the larger tubes closest to the fire, a more efficient working of the boiler would be secured; and although, if in so doing, the amount of heating surface, in a given total space for tubes, would be reduced, this loss would be compensated for by the increased efficiency. With regard to Mr. Watt's remarks as to inconvenience in working Belleville boilers when they are placed with the axes of the generating tubes athwartships and when in a seaway, I may say that, in the *Powerful* and *Terrible*, only one-third—the forward third—of the boilers are so placed; the remaining boilers in these ships, and the whole in all other ships of the Navy, are placed with the axes of the generating tubes in the fore and aft line; that is, about 264 boilers out of 296 are so placed. There are reasons in favour of the athwartship distribution of tubes, which is the plan invariably adopted up to the present in the considerable number of vessels built on the Continent with these boilers. On the whole, however, our opinion is in favour of the fore and aft distribution, as shown by our action. That the fears of the author are groundless, even when the tubes are placed in this position, is shown by the fact that all the vessels in the Messageries Maritimes Company are so arranged, and these vessels, as is well known, make regular passages between France and New Caledonia in all kinds of weather. On this subject practical experience is worth much. We know that these large ships make their ocean voyages regularly, and without any of the difficulties referred to by the author. Inquiries made on board the *Ville de la Ciotat*, which vessel arrived at Marseilles from New Caledonia last month, have elicited the information that, during the three months' voyage, there was not the slightest leak in any part of her boilers, and no repair was necessary to a single element. As regards the *Sharpshooter*, with Belleville boilers, we now have over two years' experience on actual service with this vessel, during which time many long trials have been made. No repairs whatever have been necessary to the boiler tubes. Another of the Messageries Maritimes boats had completed over 300,000 sea miles of regular steaming, with no material defects, and on returning to France, after the completion of this distance, the chief engineer reported that he could, if necessary, have left again for Australia on the following day. Coming to Professor Watkinson's paper, this, and the models he has been so good as to bring here, show us very clearly the action of the circulation of water in the various types. We were indebted to Mr. Yarrow's recent experiments with glass tubes, &c., for one fact, which I think engineers generally were not, up to that time, conversant with, viz., that by adding heat to a downcomer tube, within certain limits, the circulation was not impeded, but actually increased. Professor Watkinson has added materially to that information by showing us the limits within which this adding of heat to a downcomer tube must be kept. On page 271 of this paper it is stated, and the models confirm the statement, that when an external downcomer is used an improvement is observable in the general circulation. First, as regards the Belleville boiler, the remark is made on page 269, line 10, that in starting it is necessary to have water in all the tubes, in order to prevent overheating of the upper tubes. It is presumed that this remark refers to the glass model only, for it is certainly not necessary in the actual boiler. On page 270, with reference to the remarks that when raising steam in this boiler a water-hammer action is experienced, this, of course, is a well-known action, and is certainly experienced to a moderate extent when steam is raised very rapidly; but when raising steam slowly we have not experienced it. In certain foreign vessels it is more noticeable by noise when raising steam, but it does no harm, and there is no objection to it. Next as regards the lower part of page 273, to the effect that the temperature of the metal of the boiler tubes will be a few degrees above that of the water, also on the top of page 274, where the author assumes a difference of 100° Fahr. as an extreme case, we think the author is entirely mistaken as to the amounts of such difference met with in practice. I will give two examples; the first, was a carefully conducted experiment made on the

tank boilers of the *Vulcan*, where a gauge-rod was inserted to measure the difference between the expansion of a boiler tube and that of a rod next it of the same temperature as the boiler water. This difference gave the excess temperature of the tube beyond that of the water. It was found that, when working with an air pressure of $\frac{7}{10}$ inch of water, on a natural draught trial, the tubes at the middle of the nest were 180° Fahr. hotter than the water in the boiler. Again, a recent experiment was made to ascertain the same thing in the bottom tube of one element of a Belleville boiler. It was found that when burning coal at various rates, the increase of temperature varied from 60° Fahr. at very slow rates of combustion, to 210° Fahr. at the highest rate. This was with a clean boiler, and it will be quite understood that, when boiler tubes get a little dirty these temperatures are liable to be increased. Referring to small tube boilers, with tubes between tube plates, we know that tubes with little or no curvature do bend under service conditions, and are often found to be considerably distorted. Respecting the question of bent versus straight tubes, an important consideration also is that, no matter what precautions may be taken, there will be occasional shortness of water in such boilers, and under such circumstances the resulting damage to a boiler with bent tubes is much less than with boilers with straight tubes. On this I would remark that we have had recently some practical experience, on trials of torpedo-boat destroyers, which appears to also confirm the view that a downcomer, either external or internal, is an improvement. Three firms fitted torpedo-boat destroyers with all straight tube boilers. One firm provided small internal downcomer tubes, and the trials were successful. The other two firms fitted no downcomer, except screening off certain tubes: on one or other of the trials more or less bent tubes were experienced, showing they had been overheated. Coming to Colonel Soliani's paper, with its important suggestions, I must take exception to the modest statement personal to himself in the last paragraph of page 259, wherein he describes himself as a *dilettante* in marine engineering. I believe Colonel Soliani occupied the position of Engineer-in-Chief of the Italian Navy for some years previous to occupying his present position of Director of Naval Construction, and many eminent engineers in this and other countries are well acquainted with his high attainments as a marine engineer. Colonel Soliani has proposed a type of compound marine boiler for certain reasons which he says will be of advantage to the Mercantile Marine as well as for Naval purposes. Of the advantages to the Mercantile Marine I do not presume to advance any opinions, but concerning the purposes of the Navy it is submitted that whatever advantages this boiler contains, it certainly retains the disadvantages of large diameter and corresponding thickness of shell plates, and of large water spaces and volume of water contained. No mention is made of the pressures it is proposed to work this boiler at, but from the sketch it does not appear to be suitable for pressures in excess of 200 lbs. per square inch. The arrangement of water tubes, too, does not appear to lend itself to convenient access to the ends of the ordinary smoke or fire tubes. The reason given for this suggestion on page 258, that the vitality of cylindrical boilers may be increased and the struggle prolonged, even for Navy purposes, does not appear to me consistent with the view that progress in the direction of the use of higher pressures is desirable. It has been stated in public official papers that the Admiralty are using water-tube boilers of the small tube type for vessels of the torpedo fleet, and for special ships such as the third-class cruisers of the *Pelorus* type; and that for battle-ships, and for first and second-class cruisers, water-tube boilers of the large tube type are being adopted. There is another class of small vessel, used for what may be called river or police purposes, such as sloops, and in these I submit it is desirable also to use the large tube type of water-tube boiler. My remarks have gone to a great length, but I would add that one of our reasons for the above-named choice of water-tube boilers in the different classes of ships named is that, with the large tube, we have a fair amount of thickness to take up the wear and tear of use, and a size of tube admitting of easy examination

and correctly ascertaining its condition; and one should be able to say of such boilers that, with the replacement of an occasional tube, they should last three commissions of three years each at least, whereas with the thinner tube of the small tube type of water-tube boiler we cannot, with our present experience and knowledge, guarantee more than from three to five years of life.

Mr. A. F. Yarrow (Vice-President): I am sure the Institution is under a very great obligation to the three gentlemen for the very able papers we have just listened to, and particularly to Professor Watkinson, for his additional kindness in showing us the very interesting experiments we have witnessed. The subject these papers deal with is one of the very first importance at the present time, and the light which is thrown on the matter is therefore of special interest. I should like to draw attention to page 264 of Mr. Watt's paper, at the upper part of which you will see a statement of the evaporative efficiency of the various rows of tubes, and it will be seen that the two rows nearest the fire actually evaporate 84 per cent. of the total, the seventh row only giving one-half per cent. of the total. That there exist such large variations of the evaporative efficiency of the tubes, dependent upon their situation, has been well known to those who have made this subject one of experiment, but I would submit that frequently the rapid reduction of evaporative efficiency in heating surface, as it becomes more and more remote from the furnace, is occasionally not sufficiently realised in actual practice. In the course of our experience we have been frequently asked to submit designs of boilers, both of the water-tube and tubular types, and it often happens that a demand is made that there shall be more heating surface, even if it can only be obtained at the sacrifice of efficiency in circulation or a reduction of combustion chamber capacity; and I would point out that, the figures given by Mr. Watt are most instructive, as showing the little gain that is secured by an addition to the heating surface when that is remote from the fire. I would venture to say that frequently, perhaps generally, when extra tube surface is insisted upon, the gain by this additional heating surface is often obtained at a very much larger sacrifice, due to the loss owing to reduced circulation or to the less perfect combustion. If I am correctly informed, our friends across the Channel have long since fully realised the general principle to which I refer. In the Du Temple boiler I believe those portions of the tubes which are nearest the fire are actually reduced in diameter, so as to secure larger capacity for the combustion of the gases, although it is obtained at the sacrifice of heating surface. From the results of experiments we have made, I believe I am justified in saying that, the capacity of the combustion chamber and the means for the proper intermingling of the gases, so as to secure the most perfect combustion, should be considered as a matter of the first importance, and even before the extent of the heating surface; more particularly if that surface is in close proximity to the fire, thereby cooling the furnace, putting out the flame, and diminishing the actual heat generated. Professor Watkinson's experiments are of the deepest interest, and extend over a larger range of types of boilers than, I believe, has ever been attempted before. They serve to readily compare the rapidity of circulation in different types; but it must be borne in mind that, the experiments we have seen are all under atmospheric pressure, therefore due allowance must be made for the altered conditions under which the boiler works in practice. I believe it is correct to state that, whatever the circulation may be under atmospheric pressure, it will generally be more rapid and more permanent under high pressure. In Professor Watkinson's paper he refers to the slightly increased circulation when the tubes which enter at the bottom of the steam drum were carried above the water-level. We have tried experiments in this direction, and admit that such is the case when the tubes are carried up in the direct manner described; but I would point out that, by carrying the tubes up into the steam drum, the

difficulty of gaining access to the interior of the drum and cleaning it, and the interior of the tube, is greatly augmented. Also, water is much more apt to pass into the steam pipe through its being driven upwards along with the steam, and I differ from Professor Watkinson's conclusion that a smaller steam drum can be used when the tubes deliver at the water-level; in fact, I apprehend that the steam drum must be greatly increased in size, and must be provided with a series of baffles. I notice, from what Professor Watkinson says, that he finds an increase of circulation is caused by the heating of the tubes in which the down-currents exist, which is what I have for some time maintained. I am also pleased to find that the author gives it as his opinion that drowned tubes throughout the boiler are, for practical purposes, all at the same temperature. Those next the fire are undoubtedly subjected to greater heat than the others, but any possible increase of length, due to this increase of heat, may be disregarded. Straight tubes in water-tube boilers have now been for many years successfully used in boilers of the type adopted by us, and I believe the lowest estimate of the number of tubes of this kind now in such boilers may be put down at 200,000, and, as far as I am aware, no injurious result has been found from their adoption. Coupling this with the views expressed by Professor Watkinson, I think we may confidently say that, no one need fear using straight tubes in water-tube boilers, provided, of course, that efficient circulation is insured, and by using such tubes advantages are secured for cleaning and examining the interior of the tubes, for simplicity and cheapness of construction, and for convenience as regards spare gear; and, in addition, any impediment getting into a straight tube will fall through it, while if it get into a tube which is curved it may result in the tube becoming ultimately blocked, the impediment resting in the bends or the more horizontal part of the tube. We still continue to galvanise our tubes internally, because we believe by so doing the durability is increased. In a straight tube this may be done with impunity, because, if any of the interior zinc scale off it falls through a straight passage, while it might not do so in the case of one that is curved. I am aware there is an objection to the accumulation of hydrogen due to galvanising internally, but this is only experienced when the boiler is new, and by ordinary precautions can be completely guarded against.

Monsieur J. A. Normand (Member): My Lord, I have only a few remarks to make with regard to the splendid experiments which Professor Watkinson has invited us to witness. First of all, I beg to point out the great difference existing between models and actual boilers. Everyone knows what is called the "steam loop," a steam bubble occupying the whole section of the tube, and causing an intense circulation. The dimensions of bubbles being independent of the size of boilers, the phenomenon occurs much more easily in small tubes. Accordingly, if experiments of this kind are most valuable in giving a general idea of boiler circulation, they do not show exactly what occurs in practice. Professor Watkinson objects to the return tubes as I put them in my boilers. Although I generally give them the form objected to in order to save weight, I have sometimes lengthened the upper reservoir and placed them under. According to Professor Watkinson, this arrangement is the best.

Professor Watkinson: I did not refer to the external diameters at all, only the internal.

Monsieur Normand: I beg your pardon. Mr. Yarrow has referred to the heating tubes in some of my boilers that were of less diameter in the lower part. I did it in order that the fire should not be extinguished as soon as it penetrated through the cluster of tubes, but I consider it is a very dangerous thing to do, because anything coming down in the tubes stops when it gets to the smaller part, so that I will never more put tubes of varying diameters, the smaller part being at the bottom. It would not matter if the small part was in the upper end, but, otherwise, it is very dangerous.

Before beginning to light my boilers and to use them I am obliged to send a call through every tube to see that nothing remains in it. As to the difference of temperature between the water or steam, and the metal of the tube, I quite concur with what has been so ably said by Mr. Durston, that the difference is very great, and the best proof of that is that tubes made of pure copper—a metal able to resist high temperatures—have given such bad results. I have had to change the tubes of many boilers, and, although some of them are doing pretty well, yet I consider that the only reliable material is steel, or more especially iron, that is to say steel with as little of carbon in it as possible. As to the head of water above the upper part of the tube reducing the discharge of the steam, I do not believe it does. For instance, if you have a reservoir full of air (I have made the experiment), and if you let the air escape, the time of discharging the reservoir is exactly the same whether the escape takes place at a small distance under water or above. I do not know that I have anything more to say, except to thank you for listening to me.

Mr. J. I. Thornycroft, F.R.S. (Vice-President): My Lord, Ladies and Gentlemen, I am very much interested in these papers, and I feel that the Institution is particularly indebted to the writers for the able manner in which the subject has been put before us. The object of making the old drum boilers last longer, as proposed by Colonel Soliani, although it has great merit in many ways, I feel, for the purposes of the Navy, as mentioned by Mr. Durston, this suggestion is one in vain, and therefore I hope Colonel Soliani will excuse me if, with regard to the subject before us, I am obliged to dismiss that, at the same time saying, that I feel great regard for the pains he has taken to bring the matter before us. With regard to what Mr. Watt has said, and the model that he has brought before us, I would only say that, his models prove too much. From the figures he gives us, he says that the evaporation is reduced from about 8½ oz. to 5 oz., or figures in that proportion, by increasing the vertical, or turning towards the vertical position. It follows from that, and by experiments made by Professor Kennedy, where the tubes were at a great angle to the horizon, that it is possible to design a boiler having an efficiency greater than unity, which is impossible. But we must not dismiss the experiments of Mr. Watt entirely; because, if his experiments could determine the real effect depending on the position of the tubes, under all circumstances, they would be most valuable, and the experiments Mr. Watt has made really prove the effect of that change in this particular boiler. What he wished to do was to make a general proposition, but I must say that he only proved what took place in one particular case. With regard to what Professor Watkinson put before us, I feel I must thank him very much for taking such great pains, and endangering so many glass pipes for our pleasure. From what I have seen of these experiments at Glasgow, where I saw them in his own laboratory, under conditions more favourable, I must say I observed some phenomena there which were most interesting and instructive. Now, I would return to something Monsieur Normand said. I feel that Monsieur Normand did not quite appreciate one point which Professor Watkinson tried to make, and he had not really time to bring it before us. The effect of the increased velocity at the top of the downcomer causes vapour to be given off, and thus obstructs the downcomer. I think if Monsieur Normand has time to see that experiment he would find it very interesting. With regard to the temperature of the tubes, what Professor Watkinson said was that the difference of temperature between the two sides of the tubes was limited. Whether his calculation was correct I do not know, but I must say this, that his conclusions debar any change of temperature between the tube and the water, and although theoretically that may be very small (I do not know what it is) I think the experiments Mr. Durston gave us, showing the expansion of tubes actually measured in a real boiler, give us information, and show an amount of expansion which we certainly should not have expected,

and which are very valuable data on the subject before us; and I think they make it evident that there is more difficulty in straight tubes, which are fast to two tube plates, than is generally believed, and therefore I contend that the case has been made out for bent tubes, which I have always advocated, and which have given no trouble. With regard to the circulation in the different boilers, one of the most important points Professor Watkinson made is the fact that in the various boilers it is most important to discharge the water above the water-level in the upper drum. In a paper I prepared for the Institution of Civil Engineers I defined circulation as the orderly procession of the water through the boiler (not exactly in these words) by which a definite course is maintained; and the difficulties due to the upcomers becoming sometimes downcomers, and sometimes, as I have seen in Professor Watkinson's laboratory, to an alternating motion taking place, so that the water may alternately go up one tube and down another, result in the circulation becoming what I described many years ago as confused, and liable to lead to disaster. I feel we are very much indebted to Professor Watkinson for bringing this subject before us.

Mr. Leslie Robinson (Member): My Lord, I will not at this late hour add any remarks, but I should like to ask Professor Watkinson if he would mind repeating the explanation he gave as to the reasons that caused him to alter his opinion between his letter to *Engineering* and this present time. Some of us are still rather at sea as to his reasons for doing so, and I think some explanation would be of use to the meeting. There is one point, however, which I should like to notice before I sit down, and that is, that I think we ought to be a little more careful sometimes in running out and comparing heating surfaces. One is rather apt to talk of heating surfaces in connection with horse-power, without due regard as to how those heating surfaces are distributed, and in view of the difference in the results that have been obtained in various classes of boilers, I think it is time that a little more care and discrimination were exercised in this direction. There are heating surfaces and heating surfaces, and we should give a little more attention as to how the distribution takes place. To say that one class of boiler has so many more square feet of heating surface than another boiler of the same grate surface and same power, does not always mean that it is an easier steaming power. A great deal depends on how that surface is distributed, and on the course taken by the flames through the boiler.

Mr. J. Thom (Member): My Lord and Gentlemen, I intended to ask Professor Watkinson whether there was any necessity for increasing the circulation in a boiler to a greater extent than what it is found the boiler will work satisfactorily with. Although it is not mentioned in the paper, he explained at the finish his views on circulation, and the advantages of the greater circulation. I was interested in the circulation dispute, and last summer experimented with a steam launch 47 ft. long, built for experimenting purposes, with a water-tube boiler similar to the Niclausse type, only with the tubes at a greater angle. I tried a number of experiments to improve the circulation, and after getting it ample and efficient, I took out the internal circulating tubes altogether, to see what the result would be, without any circulation more than the spasmodic action of the steam blowing the water out of the tubes and refilling with water at intervals. I thought the simplest way was try the speed of the boat on the measured mile with circulation tubes and then without. The variation of power could be easily detected, as the speed was only 8 knots. The result was exactly the same with or without circulation. The tubes were of a diameter and length suitable for ordinary draught or a small jet of steam in the chimney. Looking at the bottom of the Belleville boiler, where nearly all the steam is generated, there is hardly any circulation in the bottom tubes; the circulation increases as it goes up, as shown by the glass model, the reverse of what one would have expected for efficiency, so

that the question arises, is it of any real advantage increasing the circulation above the desired amount to make the boiler work perfectly without giving trouble at the rate of combustion it is intended to work at? I have always found it more important to attend to the circulation of the gases than the circulation of the water, as by altering the circulation of the gases I found it made as much as 50 per cent. difference in the efficiency of the same boiler when the temperature in the funnel was reduced. Fig. 1 shows an experiment in circulation I made with a coil and straight up pipe to find whether the circulation would be up or down through the coil. I found naturally it started first up the straight pipe and down the coil, but it took very little trouble to start it either way, and whichever way the circulation started, it kept going. So I judge from that that there was about the same proportion of steam to water in the coil and in the vertical tube. So I made another experiment, connecting a top and bottom receiver with tubes of different diameters, and the proportion of water to steam would be less in the small tube when both tubes were exposed to the same temperature. In this case I found we could not reverse the current. It was always up the small tube and down the large one; so that the circulation in this style of water-tube boiler would be greatly assisted by having the ascending tubes smaller in diameter than the downcomers, where no outside downcomer was employed. In reference to the compound boiler proposal, I have had a short experience with compound boilers at sea, but the author of the first paper has left in the parts of the boiler not at all suitable for the high pressure wanted now, and taken away the combustion chamber, which is the most suitable part for high pressure, because it can be stayed to suit the pressure, and you get very efficient results, as it always keeps clean.

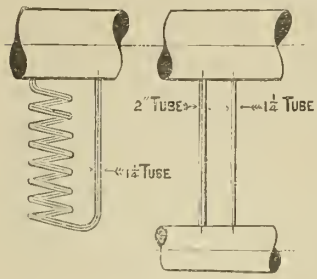

Fig. 1.

Mr. A. Blechynden (Member): My Lord and Gentlemen, I have very little to say on the subject, but I feel that since I entered this room to-night I have realised that we are very apt to draw too many general conclusions from one isolated experiment, or set of experiments. Mr. Watt's paper is a very interesting one from many points of view; especially coming, as it does, from one of our older advocates of the water-tube boiler. Much may be learned from it, but when its author deduces from his experiments with one very small model, that, in *any* water-tube boiler, the relation of the evaporation *in the row of tubes next to the fire* is 60 per cent. of the total, and that in *any* water-tube boiler, a certain angle of inclination is the best for the tubes, he goes further than the range of his experiments warrants. If, instead of the word *any*, he used the expression, "this model of water-tube boiler, and under the conditions of trial," he would be nearer the truth. The proportion of the whole evaporation done by the row of tubes next the fire is very variable, and depends, amongst other things, upon the ratio of the surface in those tubes to the whole surface of the boiler, and the temperature and quantity of the furnace gases relatively to the surface of the boiler, the distribution of that surface, and the temperature of, and pressure of, the boiler contents. But, assuming the case of a boiler somewhat similar in principle to that which he experimented with, it will be obvious that the relative amount evaporated by the various rows of tubes will vary, with two clearly marked limiting conditions, with the same quantity of fuel consumed: (*a*) When the quantity of air is limited to that necessary for the perfect combustion of the fuel, in which case the temperature of the furnaces would be a maximum, and the quantity of the gas resulting from combustion a minimum; and (*b*) when the quantity of air supplied is so much in excess of that necessary for perfect combustion, that the process is just possible, in which case the temperature would be a minimum,

and the quantity of the resulting gas a maximum. It will be obvious that, in the latter case, if the quantity of fuel consumed is very large relatively to the surface of the boiler, each row of tubes would approximately evaporate the same quantity ; and that, in the former, by far the greater proportion of the evaporation would be done by the inner row next the fire ; and that, as there is room for a very great number of variations between those limiting conditions, as well as in the quantity of fuel consumed, no such general rule as that laid down by Mr. Watt can be correct unless he limits his condition to one state of things. A case occurs to me in which temperature measurements were made in the centre, and at the exit side of a group of tubes inclined at an angle of about 50° with the horizontal, which bears on the point :—

Temperature of atmosphere	70°
Temperature in centre of group	about 1,200°
Temperature at outside of tubes	800 to 850°

The coal had a calorific value of about 13,500 B.T. units, and the evaporation per lb. of coal was equivalent to 8·38 lbs. from and at 212°. The pressure of the boiler was about 200 lbs. per square inch. A very little calculation will show that the evaporation in the outer half of the group of tubes must have been nearly 20 per cent. of the total, rather than the 6·5 as estimated by Mr. Watts. The same conditions, to a very great extent, determine whether in a boiler, with steeply inclined generating tubes, and no special outside down tubes, there will be a rapid down current in the outer tubes, and efficient circulation, or whether there will not. If the furnace temperature is relatively high, and the surface large, so that before the gas reaches the outer row of tubes its temperature is lowered sufficiently to give rise to no very rapid generation of steam in them, in all probability the circulation will be determined and efficient ; but if the surface is not of such proportion, relatively to the quantity and the temperature of the gases, as to absorb sufficient of the heat to prevent very rapid evaporation in the outer row of tubes, the probability is that the circulation will not be determined and efficient, and that the water will be driven from them, and their only supply will be spasmodic and between the explosions of steam from them. It appears to me that the efficiency of any water-tube boiler depends on the quantity of water in the tubes as much as on the circulation itself ; but I shall not further refer to this matter, as it has already been fairly thoroughly discussed in these meetings after Mr. Thornycroft's paper of some years ago. It seems very probable that the decrease of efficiency of heating surface, after the inclination of the tubes exceeded the angle of 10° in Mr. Watt's experiments, may be fully accounted for by the tendency of the heated gases to rise to the top of the furnace, and to flow outwards across the upper portion of the tubes, for the time being, thus ceasing to come in contact with the gradually increasing portion of the group of tubes at the outer and lower corner. This conjecture is rendered the more probable by the fact that, in Mr. Watt's later experiments, the increased inclination had not so very marked an effect on the single and portable series of tubes, which he describes as having been placed next to the fire. As I understand the diagram, the evaporation was the same in absolute quantity in this single series of tubes at both 10° and 80° inclination. I observe that Mr. Watt gives expression to the common though incorrect opinion that, as heating surface, a copper plate is more effective than iron or steel. A clean copper plate is not nearly so good a transmitter, or perhaps rather receiver, of heat as a steel or iron plate, all being just as they come from the mill. This may be easily proved by anyone who will take the trouble to place a clean copper and a clean steel pan over the same coke fire, when it will be found that the steel will evaporate about three pounds for two of the copper ; but if the surfaces of the two be smoked, the quantities evaporated will be the same in each case.

Professor Carlton Lambert (Associate): My Lord, I do not propose to take up the time of the meeting for more than two or three minutes, as it is getting so late, and, moreover, I am not competent to discuss many of the interesting things that have been talked about. I would like to say a word in reference to what Professor Watkinson stated with regard to the assistance rendered to circulation by heated downcomers. I notice that on page 274 of his paper he has said that "With a given rate of evaporation from a given amount of heating surface the greatest velocity of circulation will be obtained when all the heat is supplied to the upcomers; but if additional heat be applied to the downcomers, the velocity of circulation will be increased, so long as the amount supplied to the downcomers is insufficient to generate steam with sufficient rapidity to nearly exclude continuous water at some part of the downcomers." I think, however, that if we study the matter we shall see that such a limit as he here fixes, and to which Mr. Durston has alluded, if existing theoretically, would hardly be approached and certainly would not be reached in practice. Those of us who were fortunate enough to witness the brilliant series of experiments by which Mr. Yarrow lately demonstrated the phenomena of circulation in water-tube boilers, will remember one particularly striking experiment with a boiler working at 150 lbs. pressure, wherein it was shown conclusively that, after a vigorous circulation had been set up, every addition of heat, whether applied to an up or a down tube, increased the velocity of circulation, and that it was even possible to maintain a vigorous circulation, when all the heat was withdrawn from the up tubes and only the downcomers were heated. That was of course, a startling experiment, and it went to prove what, I am glad to see, Professor Watkinson has corroborated, and what some of us who at the time took part in the controversy that was carried on in the columns of *Engineering* advocated, viz., that heat applied to the downcomers did not impede circulation but actually increased it. Now with regard to the limit fixed by Professor Watkinson, I believe that, far from there being any possibility of so rapid a generation of steam in a heated downcomer as this limit implies, as a matter of fact rarely, if ever, is there any generation of steam at all in a heated downcomer in practice, and this for two good reasons, viz., that the down tubes are so far from, and so well shielded from, the fire, that they have very little evaporative efficiency, and, secondly, bubbles tending to form would be suppressed in their descent by the increasing pressure. Personally I have never seen bubbles in a down tube, either under high or low pressure; but possibly they may have been seen when a down tube has been violently heated. If in Mr. Yarrow's experiment, where the pressure was about 150 lbs.—more like the working conditions of an actual boiler—there were no bubbles seen in the down tube, we may surely say that Professor Watkinson's limit would never be reached in practice, and we may infer that circulation is always improved by having the downcomers in the fire. I wish Professor Watkinson had been able to carry out some experiments under high pressure, because it does seem to me that the deductions to be drawn from experiments made under atmospheric pressure only cannot be relied upon to prove what will happen under working conditions. The Yarrow experiments showed considerable difference in the character of circulation under high and low pressure. The alternating actions which were visible under low pressure rarely occurred under high pressure; in fact, it was evident that circulation under high pressure was always more steady than under low pressure. I hope it will not be thought ungracious if I venture to criticise unfavourably a part of Professor Watkinson's paper which he did not read. In the remarks on pages 267 and 268, giving the theory of the cause of circulation, Mr. Watkinson has taken three different cases. In the first, when the fires are first lighted, and before steam is generated, he states that the circulation is due to the difference in density of the contents of the up and down tubes. Of course we all agree with that. His third case is "when steam is generated with such rapidity that in some part of the circuit there is steam or foam only present," and he

ascribes the circulation in this case also to the difference of the mean density of the contents of the two tubes as in the first case. So far I agree with him; but when he takes the intermediate case, he finds a new cause of circulation, viz., the entraining action of the bubbles upon the water. I understand the words "entraining action" to mean the frictional drag which the bubbles exercise on the water as they are forced upwards through it. I believe that the cause of circulation in the intermediate case 2 is exactly the same as in cases 1 and 3, viz., simply the difference between the mean densities in the up and down tubes. Now what about this entraining action of the bubbles on the water? It cannot be the cause of circulation, for it is necessarily accompanied by an equal reaction of the water on the bubbles in the opposite direction. Here are two equal and opposite actions practically annihilating each other as far as their effect on the whole mass, water and steam, is concerned. How then can the observed results, namely, the lifting bodily of the whole contents of the up tube, be produced by an internal action between its own parts? I do not think that Professor Watkinson's illustration of a string of beads dragged up and down in a tube, and thus producing circulation, is at all applicable. Here he is using an outside force to make his circulation, but in the boiler tubes the cause assigned is an internal one. Surely the two cases are not comparable. Professor Watkinson will, I am sure, forgive this criticism of part of his paper. Perhaps he did not read that part, because he thought that it might be open to some little criticism—I do not mention this unkindly—but it is just possible that, as he has altered his mind on one or two other little points, he may have modified his views on that too, and may after all agree with me.

Mr. C. Humphrey Wingfield (Visitor): I think that the distinction the author drew between the effect of bubbles so close together as to form foam, and those which were sufficiently separated to allow the column of water to be continuous, was unwarranted by the facts. Fig. 1 represents a tall

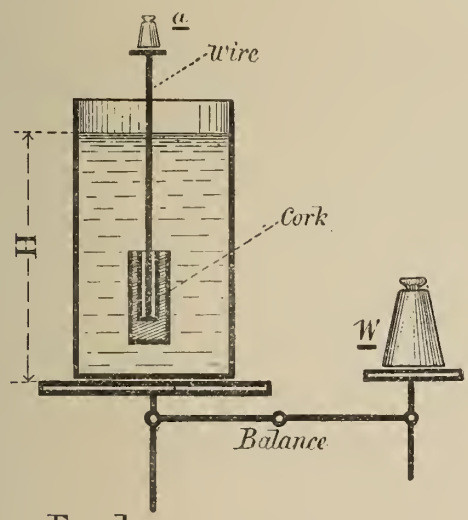

Fig. 1.

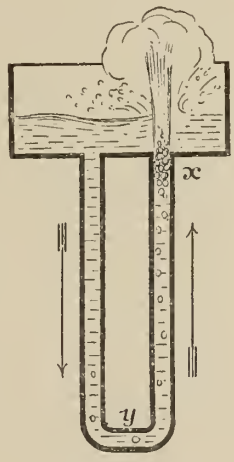

Fig. 2.

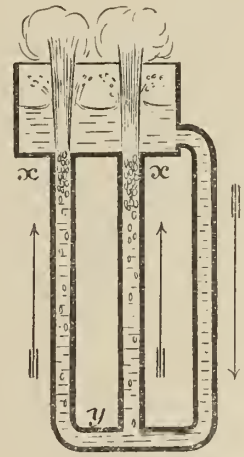

Fig. 3.

vessel of water supported on a balance. A cork placed below the surface of the water is prevented from rising by a wire fitting loosely in a hole made for the purpose. A definite pressure, which may be represented by a weight a, is required to prevent the cork rising, and the whole is counterbalanced by a weight W. The latter weight would be the same whether the wire was pressed down by a weight or

held by the fingers. On suddenly removing the wire the cork is free to rise—thus representing a free bubble. The previous condition of equilibrium is disturbed, the water appearing lighter than before, and when the cork has attained a uniform velocity it will be found that the weight a (including the weight of the wire) will just restore the balance, if placed in the same scale-pan as the vessel of water. When the cork (bubble) is held down by an external force (as in the author's string of beads, for instance) the pressure on the bottom of the vessel will be found exactly equal to that due to the static head H. As soon as it is set free the pressure on the bottom is less, although the continuous head is unchanged. This proves that every single bubble in a given tube contributes its share towards lessening the effective head in that tube. Those in downcomers (if present) tend therefore, in all cases, to reduce the circulation; while those in the rising current tend, by reducing its weight (and not by "entraining" action, which I believe to be imaginary, except where an external force is applied, as in a chain-pump, or the author's string of beads), to increase its velocity. Professor Lambert had referred to the circulation in a "U" tube, such as sketched in Fig. 2, page 287. By some very pretty experiments Mr. Yarrow had proved that, if not forced too hard,* circulation, as shown by the arrows, may be maintained without special downcomers. There would be more bubbles at x (Fig. 2) than in other parts of the tube, and, if evaporation were increased till the tube was on the point of being overheated, the proportion of bubbles to solid water at this point would be at a maximum. Steam would then issue from one leg of the tube at the maximum rate consistent with safety. Fig. 3 represents a boiler consisting of two steam-generating tubes of the same diameter and length (x y) as the two legs in Fig. 2; but, in this case, a downcomer is provided. When heat is applied to the steam-generating tubes till the bubble density at x is the same as in Fig. 2, they will also be on the point of breaking down by overheating. In this case, however, *each* of the two legs would eject steam at the same rate as the *one* leg in Fig. 2, although the heating surface is precisely the same. Hence, when a downcomer is fitted to a given boiler at least twice as much steam can be safely generated per hour as would be the case with the same boiler without downcomers. In other words, with a given rate of steam production the liability to failure by overheating is at least twice as great without special downcomers as it is when they are provided.† Reference had been made to the use of copper as a material for boiler tubes. It is becoming well known that it is an untrustworthy material for this purpose, and its failure is sometimes attributed to bad material or to its becoming burnt. Last year Mr. Milton read a paper before this Institution on "Copper Steam Pipes," in which he showed that tough copper contained a certain percentage of oxygen, and that the kind of injury during manufacture frequently attributed to "burning" (which meant, of course, oxidation) was really due to an exactly opposite cause—de-oxidation by the reducing action of a smoky flame containing imperfectly consumed gas. Smoky flames are met with in boilers—occasional puffs of flame from the funnels attest a want of sufficient oxygen in the firebox to complete the combustion, and is it not possible that the brittleness of copper boiler tubes may be due to a similar action—de-oxidation by a reducing flame?

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* An experiment described by Professor Watkinson in his reply showed that, at moderately high rates of working, the "circulation" with a "U" tube was unstable, becoming oscillatory.

† In an actual boiler without special downcomers the bubbles, or heated water, from more than one casual downcomer might enter a single rising tube. In this case the maximum safe bubble-density at x would be reached in some tubes when others are comparatively free from steam, so that the safe steaming rate was *less* than half that which could be obtained with a more perfect circulating system; such as provided in the Thornycroft boiler, for instance.

Professor W. H. Watkinson (Associate): I should like, my Lord, to say a word or two in connection with the papers read by Colonel Soliani and Mr. Watt, if I may be allowed to do so. The greatest weakness of the water-tube boiler is, I believe, that if a tube fails it cannot readily be plugged, as is the case in a fire-tube boiler. The redeeming feature of the water-tube boiler, so far as this point is concerned is, that the total amount of water in the boiler is small. If we compound a boiler in the way proposed by Colonel Soliani, we have a boiler containing a large quantity of water, and still we cannot readily plug defective tubes. The proposed boiler, therefore, although very interesting and ingenious, seems to be a very undesirable combination. Mr. Watt concludes that the outer tubes of water-tube boilers are of exceedingly little use, so far as the generation of steam is concerned. I believe that is a very great mistake, and a very common one. If the gases are well mixed, and if they move quickly enough, then, with the exception of the tubes exposed to the radiant heat, all the tubes will do approximately the same amount of work, no matter how far removed from the fire they may be. That this must be the case is evident from the fact stated in my paper, that a difference of temperature of $2\frac{1}{2}^{\circ}$ Fahr. between the inside and the outside surfaces, for each $\frac{1}{16}$th inch thickness of tube, is sufficient to enable 20,000 British thermal units to be transmitted per hour per square foot of tube surface. If the gases are not properly mixed, and if they move too slowly, this difference of temperature will, of course, not be maintained.

Colonel W. Soliani (Member): My Lord and Gentlemen, I shall begin by replying to Mr. Durston, who made the more important remarks on my paper, and in such a kind way. He said the compound boiler had the disadvantage of having, like the ordinary marine boiler, a large diameter, which prevented the pressure being increased over a limit of about 200 lbs. per square inch, while a great increase of pressure could easily be carried out, and was carried out, with the water-tube boiler. On this point I think he is quite right, as evidently, in regard to working pressure, the compound boiler would practically be in the same condition as the present marine boiler. There would be no progress in the direction of higher pressure; but it seems to me that, for reasons that are quite independent of the type of boiler, the increase of pressure above 200 lbs. is necessarily slow, and is not likely to greatly affect the struggle of which I speak in my paper. Of course, other advantages of water-tube boilers for Navy purposes are of so much importance that the final issue is certain to be in their favour; but, nevertheless, the possibility exists of a vital competition between the two types of boiler, as is apparent from the fact that in some war-vessels a combination of water-tube boilers and ordinary marine boilers has been resorted to. This shows that there is something lacking in the water-tube boilers to make them thoroughly adapted to the multifarious exigencies of service at sea; a something which is still to be found in the ordinary marine boiler. The combination of the two kinds of boilers in the same ship shows also that the disadvantage of not being able to increase the steam pressure is not deemed to be of so much importance as to outweigh the convenience of having ordinary marine boilers on board. As I said in the paper, the water-tube boiler is certainly, for small and fast vessels, a necessity and an accomplished success. My contention refers to mercantile ships and to big Navy ships. In ironclads, for instance, when it is necessary to have armoured protection over all the machinery space, the ordinary marine boiler lends itself to a more compact arrangement, and may render possible a considerable economy of weight. In addition to this, the ordinary marine boiler offers the advantages over the water-tube boiler of a greater regularity of steaming and greater concentration of power, both of which are desirable things, whether the ship is a man-of-war or a mercantile vessel. Perhaps concentration of power may be more valuable in merchant ships: if we compare the *Powerful* and the

Campania, which have approximately the same horse-power, we see that in one, the *Campania*, there are only, if I remember rightly, twelve boilers, while in the *Powerful* there are forty-eight, viz., four times the number. It means also four times the number of steam valves, feed valves, gauge glasses, and all other boiler fittings, which multiplication means increased chances of derangement and increased supervision. But, as I expressed it in the paper, although Mr. Durston kindly thinks otherwise, I am only a *dilettante* in my engineering; I have never constructed a boiler myself, nor have I the experience at sea that Mr. Durston and most of the members have; therefore much value cannot be attached to my view. It is only an opinion which I have frankly expressed to you, and Mr. Durston may be quite right in all his remarks. Mr. Thornycroft kindly made some remarks on my paper which I have not well understood, but I think on the whole he did not approve much the compound boiler. He also may be right.

Mr. Thom: One of the compound boilers had to be taken out after being three months in a ship.

Colonel Soliani: It may be so, but as mine is only a boiler on paper, it does not want to be taken out, it should be made and tried. You must realise that I am myself a believer in the water-tube boiler. As I have said clearly in the paper, I think it is only a question of time and nothing else. I believe myself that whatever may be the drawbacks to water-tube boilers they will be overcome, and the final success will be for the water-tube boiler. My views refer to this transitional period only. The remark made by Professor Watkinson regarding the water tubes of the compound boiler is a right one. The compound boiler has no doubt the defect of giving up, to a certain extent, a very good feature of the ordinary marine boiler, viz., the possibility of being able to plug a damaged heating tube while the boiler is steaming, without stopping for one moment the working of the boiler. But this imperfection, due to the partial adoption of water tubes, is counterbalanced, as Mr. Thornycroft has kindly pointed out to me, by the suppression of the flat water walls of the combustion chamber, which are a weak point in the ordinary marine boiler. I think I have said enough in support of my weak view, and now I come to the most important part of my remarks, and it is once again to say that I feel most obliged to members of the Institution, beginning with you, my Lord, for the kind welcome you have given me, and which not only has given great pleasure to me, but will be heard with pleasure by my colleagues at home, many of whom are members of the Institution. They are more than half a dozen; one of them has been kindly accepted by your Council at this meeting, and one I had the honour to propose to-night. My Lord and Gentlemen, I thank you again most cordially.

Mr. J. Watt (Associate): My Lord and Gentlemen, I will not detain you many minutes. Mr. Thornycroft mentioned that he thought in the experiments I had conducted I had proved too much; but these experiments were conducted on nearly the same principle throughout, the same fair play to one experiment as to another. The difference between the angles of the tubes—a few degrees—could not in any way affect the result; that is to say, I got a certain evaporation at, say, an angle of 10°, if I altered that angle to 20° or 30° I got a different, amounting to a less result. Mr. Thornycroft has not shown why this difference took place. Mr. Blechynden, again, attempted to show us what he considered to be the cause, that when the boiler was angled to such a degree the whole of the heat passed towards the top to the disadvantage of the bottom. Now, I tried experiments in various ways, and had the funnel placed at the bottom end, so that instead of the heat getting to the top it got to the bottom, but with still the same result. So that Mr. Blechynden's explanation is entirely wrong. The true explanation will be found in what is taking place inside of the tube. I have also said in my paper that the results that I got were similar to what you obtained in an ordinary boiler with vertical

heating surface, and that is, as those who are acquainted with the subject well know, that 2 sq. ft. of vertical heating surface is only about equal to 1 sq. ft. of horizontal surface. And this compares favourably with the results I obtain with my boiler in ordinary daily use. Gentlemen, I beg to thank you for the kind manner in which you have heard my paper.

Professor W. H. Watkinson: My Lord, Ladies and Gentlemen, the difference of temperature between the inside and the outside of the tubes, when made of steel, is as stated, $2\frac{1}{2}°$ Fahr. under the conditions given; but if there is a bad circulation there may be a great difference between the temperature of the inside of the tube and the temperature of the stuff in the tube, steam or water; and in the experiments mentioned by Mr. Durston it is probable that the circulation was not sufficiently good to render the temperatures of the tube and of the water approximately the same. The more rapid the circulation the more nearly do these temperatures approximate to each other, and with clean tubes and ample circulation I think I may say that there is absolutely no uncertainty as to the difference in temperature. The best way to determine accurately the thermal conductivity of metals is by making an experiment on the flow of heat through a long rod, and determining the temperature at different points. From constants determined in that way I calculated the difference in temperature. If we have good circulation the difference in temperature can never rise to the 100° Fahr. assumed for my calculations.

Mr. Durston: I do not profess to say whether there was a good circulation, or a bad one, in the the cases I tried, but the expansion of the tube was taken, and from the actual expansion of the tube itself its mean temperature was calculated. That showed the increase of temperature I mentioned, and not the relatively low temperature which Professor Watkinson has given us. I do not say that what he says may not be correct as between the inside and the outside temperature, but not the mean temperature of the water and the temperature of the steam in which it is contained.

Professor Watkinson: I fully appreciate the importance of Mr. Durston's statement, but I venture to say that in the case he mentions the water must have been driven out of contact with the tubes. Mr. Durston's remarks regarding bending of straight tubes, when fastened directly between two tube-plates, seemed to imply that bending does not occur when the tubes are free to expand. Bending of the tubes does, however, take place in boilers of the Belleville type, for example, although the tubes are free, or are supposed to be free, to expand. Mr. Yarrow objected to discharge above the water-level, on account of the method adopted in my model boiler of obtaining that discharge above the water-level. That method is not adopted in any actual boiler, so far as I know, and I did it simply to be able to compare the circulation under the two different conditions. Mr. Yarrow also remarked that the tubes in the Thornycroft boiler are liable to over-heating during the time the boiler is being warmed up. I explained in my paper that, owing to no circulation taking place at the beginning, steam is generated almost immediately the fires are lighted, and plugs of water are projected, intermittently, through the upper parts of the tubes into the steam drum, and, as mentioned in the paper, this is of the greatest importance in preserving the portions of the tubes above the water-level from getting over-heated. My own experiments seem absolutely conclusive for the actual case of water and steam, and I shall be delighted to show them to Monsieur Normand after the meeting closes. Mr. Leslie Robinson asked why I changed my opinion with regard to the circulation being better without the downcomer. In the earlier stages of my experiments I estimated the velocity of flow by simple observation of the tubes, when the downcomers were in circuit, an they were shut off, and the results seemed to show th at

the circulation was more rapid without downcomers; subsequent experiments, under different conditions, seemed to give the opposite results. I was thus led to consider the matter more fully, and to arrange means for determining accurately the velocity of flow under the different conditions. The method adopted, and described in the paper, showed clearly the increase in the velocity of circulation due to moderate heating of the downcomers, and it follows directly from this, that the velocity of circulation must be greater when the whole of the downcomers are heated, than it is when unheated external downcomers are used. It does not follow from this that the *amount* of water circulating is less when external downcomers are used, because, although they reduce the head available for circulation, they also reduce the joint resistance of the circuit, and thus they may increase the total amount of water flowing. External downcomers, if properly proportioned, ensure, under all conditions, a plentiful supply of water to the lower drums, whereas this is not always ensured without them. Mr. Thom referred to experiments he made with his boiler without the internal circulating tube. Tubes may be made to stand if there is nothing but steam in them. In the modern superheaters the tubes stand, although they are arranged with the flames playing directly on them. It is simply a matter of the rate of working, and the length of tube. When there is no circulating tube the water in the tube simply jumps up and down, and sufficient water falls down through the steam to prevent the tubes being overheated. Now, I wish to refer to some of Professor Lambert's remarks. I did not leave out that part of the paper which he referred to because I had changed my mind, and I have not yet changed it. I left it out because I believe it to be of the least importance, and because I wished to save time. It does not matter a great deal, so long as you get good circulation, whether it is correctly described as being due to entraining action or difference in density. All good circulation is due to discontinuity in the uptake column, and in most cases it is due to the pressure of foam in the upper part of that column, and not to alternating plugs of steam and water. I was very much surprised at Professor Lambert's statement that he never saw steam formed in the downcomer. The only explanation I can give of that is that he did not apply sufficient heat to the downcomer. If sufficient heat is applied steam is generated in the downcomer, which may stop or reverse the circulation. I made several experiments in connection with this point: I applied heat to the upcomer, and got a circulation in the usual way. I then applied heat to the downcomer, and got increased circulation, just as in Mr. Yarrow's beautiful and interesting experiments. Then I applied more heat to the downcomer, and the circulation was suddenly either reversed or stopped. When the supply of heat was approximately the same to both upcomer and downcomer, the circulation did not re-establish itself, but sufficient water fell through the steam and foam into the tubes to make up for the amount evaporated. I think and hope I have replied to everyone, and I beg to thank you most sincerely for the kind reception you have given to my paper.

The President (the Right Hon. the Earl of Hopetoun, G.C.M.G.): Gentlemen, I ask you to accord a hearty vote of thanks to the three gentlemen who have contributed the very interesting papers which we have had this evening.

THE NON-UNIFORM ROLLING OF SHIPS.

By R. E. Froude, Esq., F.R.S., Associate Member of Council.

[Read at the Thirty-Seventh Session of the Institution of Naval Architects, March 27, 1896; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

§ 1. At the London Meeting of this Institution in 1894, a paper was contributed by the eminent M. Emile Bertin, on "Rolling on a non-Synchronous Wave." He followed up this paper by one continuing the same treatment, read at the Paris Meeting of last summer.

The subject of rolling on a non-synchronous—or, as it has sometimes been termed, a "disperiodic"—swell, is one to which I myself had to give careful attention in 1884, in considering the practical bearing of the results of the experiments on the water-chamber of H.M.S. *Edinburgh;* and some of my conclusions are briefly referred to in Mr. Watts' paper of 1885, on those experiments.* I soon afterwards recurred to the theoretical study of the subject, and developed a more systematic and comprehensive treatment; but have hitherto lacked occasion and opportunity to make the results public. It so happened that M. Bertin's paper of 1894 had to be taken as read, and though I fully intended to contribute a paper on the subject at the last Spring Meeting, I had not leisure to do so.

§ 2. I agree with M. Bertin that the theory of non-synchronous rolling has hitherto received too little attention. My father, the late Mr. William Froude, in his paper contributed to our Transactions for 1861, gave, it is true, a perfectly sound and comprehensive solution for *unresisted* rolling, whether in a synchronous or non-synchronous swell; and for *resisted* rolling, his subsequent papers, as well as those of Professor Rankine, give perfectly sound and very simple solutions for the uniform rolling (which in that case is also the maximum rolling) in a synchronous swell, and also for the uniform rolling in a non-synchronous swell.† But the insufficiency,

* Trans I.N.A., Vol. XXVI, p. 39.

† See Rankine "On the Action of Waves upon a Ship's Keel," Trans. I.N.A., Vol. V. p. 20; also Froude "On the Practical Limits of the Rolling of a Ship in a Seaway," *Ib.* Vol. VI. p. 175.

for practical purposes, of the last-mentioned solution lies in the circumstance that this uniform rolling is only correct for a particular "phase"-relation between the rolling and the waves, and in a non-synchronous swell may be greatly exceeded by the maximum non-uniform rolling.

§ 3. If indeed the swell be itself perfectly uniform, as is assumed by the usual mathematical treatment, then, however much the initial phase-relation may differ from that proper to uniform rolling, and however non-uniform initially the rolling may consequently be, the resistance to the rolling must gradually introduce uniformity* and establish the phase-relation proper to uniform rolling; and this the more quickly the higher is the scale of resistance. But in practice, with ordinary resistance, and an ordinary non-synchronous swell, there is always, or nearly always, sufficient non-uniformity of swell to defeat this operation and maintain the non-uniform character of the rolling †; and, when this is so, the maximum rolling exceeds that assigned by the formula for uniform rolling, which must therefore, if taken nakedly, be accounted a delusive guide.

§ 4. The method of "Graphic Integration," described in my father's paper of 1875, will give a practically correct solution for any supposed series of waves and any resistance of ship; but the labour of applying this method to any extensive series of test wave-systems is practically prohibitive. We therefore certainly stand in need of some sufficiently rapid and comprehensive, if less accurate, calculus, for reviewing the effect of a large variety of typical conditions, and so enabling us at least to make a discriminating selection of a few specially instructive test cases to be submitted to the more accurate process of graphic integration.

§ 5. Although, for these reasons, I fully sympathise with M. Bertin's object, I regret that I cannot equally concur in the means by which he seeks to attain it. To begin with, I am bound to say that, even in its professed character merely, his method strikes me as needlessly retrograde. But, even were there a sufficient case for superseding the time-honoured mode of mathematical analysis by a synthetic method, still, unless such synthetic method is to be rigorously elementary, as is the method of graphic integration, the departure from the beaten track involves grave danger of ignoring some essential element of operation; and this danger M. Bertin has not escaped.

His method purports to be a kind of flying graphic integration, a complete roll being dealt with in each single step, instead of in a succession of minute steps. The effect of the successive waves to increase or diminish the amplitude of rolling, is estimated with regard to their phase-relation with the roll; this, however, not by aid of the

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* *Vid. inf.* §§ 33, 34.

† *Vid. inf.* § 35, and footnote *, page 306.

established propositions of harmonics, but by a make-shift hypothesis,* which is tentatively put forward as possibly requiring correction later on. As to this, I must protest in passing that, if we must use a hypothesis which is to be subject to correction later on, it is better to begin with one which we know to be correct for certain definite and, at least, fairly instructive conditions, rather than one which we have no reason for supposing to be correct for any instructive conditions at all. But a far worse defect remains; for, while the immediate effect of the phase-relation upon the increment of angle of roll is thus taken account of after a fashion, no account whatever is taken of its at least equally important complementary effect, to modify the period of the roll, and consequently the phase-relations for all subsequent rolls. And this omission appears quite fatal, not merely to the quantitative accuracy of the results, but even to their general instructiveness by way of analogy.†

§ 6. M. Bertin's apparent reason for thus passing over the existing science of the problem, and attacking it *de novo* with the seemingly primitive weapons to which he studiously confines himself, is that this science is based on "the mathematical integration of the differential equation of the rolling," in which "very variable co-efficients are assumed as being constant," and "inadmissible assumptions" made about the passive resistance. Concerning the resistance I shall have something to say presently; and will here only remark that on general principles it is generally at least as easy to correct a result which has been obtained with a definitely incorrect assumption, as it is to estimate afresh with a correct one. For the rest, setting aside the assumptions of isochronism of ship and uniformity of swell, both of which M. Bertin also adopts, the only assumption required by the mathematical integration is that the momentary heeling-moment due to the waves varies harmonically in point of time. As to this, I will remark in the first place that this assumption is undeniably legitimate for a low swell ‡; and that the rolling in a low swell is, to say the least, typical and very instructive, seeing that it is the limiting

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* Trans. I.N.A., Vol. XXXV. p. 191, equations (5) and (6). On harmonic principles we should have (for an approximately synchronous swell, at least), using M. Bertin's notation—

$$\delta\,\psi = \Delta\,\psi \cos\left[(1-q)\,\pi\right]\ ;\ \textit{vice}\ \Delta\,\psi\,(2\,q-1),$$

as by M. Bertin's hypothesis. These two values for $\delta\,\psi$ agree for $q = 1$, differ more than 20 per cent. for $q = \frac{7}{8}$, and more than 40 per cent. for $q = \frac{3}{4}$, and agree again for $q = \frac{1}{2}$.

† Perhaps more so to the latter than to the former. For the special purpose of computing what I have termed the "criterion amplitude" (*vid. inf.* §§ 37—39) under conditions of only moderate non-synchronism, the method may conceivably give results of serviceable utility.

‡ The profile of the waves composing a uniform swell in deep water theoretically approximates to a harmonic (or "sinusoidal") curve as the height becomes small relatively to the length. But see also note*, to § 10, below, as to the effect of "hydrostatic tension."

case into which the rolling under other conditions tends to merge, in proportion as the peculiarities incidental to peculiar steepness of swell are eliminated. Hence we may truly say that while, on the one hand, a treatment which is correct for a low swell may in strictness require some quantitative correction if applied to a specially steep one, on the other, no treatment can be generally correct, or in any way instructive, which is altogether incorrect for a low one. And according to this criterion M. Bertin's method stands plainly condemned by its results, as anyone can see who compares his results for unresisted non-synchronous rolling with those given for similar conditions in my father's 1861 paper.*

§ 7. But, in the second place, we are in no way bound to regard the mathematical integration as if it were a sort of secret machine with concealed works, which we can use for no purpose except precisely that for which it was adjusted when sent out of the factory. And if (to pursue the metaphor) we take the machine to pieces and examine its works, we find that the assumption of harmonic wave motion is in no way essential to the principle of the solution. The assumption simply restricts the field of application

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* Or, more clearly, in the Appendix to that paper, which appears in the Transactions for 1862 (see Vol. III. p. 47. Compare with Bertin, Vol. XXXV. pp. 188—193).

Observing that $\frac{\Psi}{\Theta}$, $\frac{T_n}{T}$, *apud* Bertin, correspond to $\frac{\Theta}{\Theta'}$, $\frac{T}{T'}$, *apud* Froude, we get m (Bertin) $= \frac{p}{2(p-q}$ (Froude), and—

$$\frac{\Psi}{\Theta} = \frac{2q-p}{2(p-q)} K^2;$$

as compared with—

$$\frac{\Theta}{\Theta'} = -\frac{2q}{2(q-p)} \text{ (Froude).}$$

Hence we get—

$$\frac{\frac{\Psi}{\Theta} \text{ (Bertin)}}{\frac{\Theta}{\Theta'} \text{ (Froude)}} = \left(1 - \frac{p}{2q}\right) K^2 \quad . \; . \; . \; . \; (1 . a)$$

a ratio which varies from—

$$= 0 \text{ for } \frac{T}{T_n} = 2{\cdot}0, \text{ or } {\cdot}14\,K^2 \text{ for } \frac{T}{T_n} = \frac{12}{7}, \text{ to } {\cdot}44\,K^2 \text{ for } \frac{T}{T_n} = \frac{10}{9}$$

(the last two conditions being ones to which special attention is drawn by M. Bertin at top of page 193).

There seems, indeed, some confusion in the description of the treatment, since $2m$ (Bertin, p. 188), expressed as $= \frac{T_n}{T_n - T}$, is described as the number of rolls (of period T_n, *i.e.*, the ship's natural period), which brings back the agreement between the movements to the same point as the start. The expression, however, denotes, not the number of *rolls* (of period $2\,T_n$), but the number of *waves* (of period $2\,T$) which effects that result. The number of *rolls* is expressed by $\frac{T}{T_n - T}$, equivalent (in Bertin notation) to that for n in the present paper (*vid. inf.* § 33). But this error, if indeed it be more than verbal, cannot be answerable for the failure of agreement with the harmonic solution for unresisted rolling, s nce substituting this value in the equation for $2\,m$ makes the agreement worse instead of better.

of that principle, in a way which is requisite indeed for obtaining exact quantitative results by a purely algebraic method, but only for that purpose. And by that principle, without that restriction, those extremely fertile general propositions, which M. Bertin shuns because they have been generally treated merely as deductions from the mathematical integration, may be directly deduced in an analogous but quite elementary way. To show this is one of the chief objects of this paper.

§ 8. Assuming then, with M. Bertin, that the ship is "isochronous" in still water, and neglecting resistance for the present, as he also does at the outset, we may express the dynamic conditions for still water by the equation—

$$\alpha = -k\theta; \qquad (1)$$

where α = the momentary angular acceleration of the ship; θ = her angle of inclination; and k a (positive) constant.

§ 9. Next, not to commit ourselves to any assumptions as to the nature of wave motion, let us simply define its effect on the ship as a factitious addition (algebraic) to her momentary still-water angular acceleration, of amount $= k\theta'$; where, for convenience, we may term θ' the momentary "wave-slope," using the words, however, in a purely conventional sense. We may then write, for wave water,

$$\alpha = -k(\theta - \theta') \qquad (2)$$

For the present we will assume no restrictions as to the variation of θ' from moment to moment.

§ 10. Now imagine three ships, A, B, and C, all having the same value of k, A being in still water, and B and C identically placed in one and the same swell, so that the momentary value of θ', whatever it may be, is always *common to both.** For these three ships respectively, at some given instant of time, let—

$\theta_A, \theta_B, \theta_C$ = the respective angles;
$\omega_A, \omega_B, \omega_C$ = the respective angular speeds;
$\alpha_A, \alpha_B, \alpha_C$ = the respective angular accelerations;

* I must acknowledge that this statement, coupled with equation (2), somewhat falsifies the profession at the commencement of § 9, viz., that we are not committing ourselves to any assumption as to the nature of wave motion. In effect it is tacitly assumed that the wave motion cannot affect the term $k\theta$, which nevertheless it does, in virtue of the difference in what has been called the "hydrostatic tension") between the crest and trough regions of the wave. (See Trans. I.N.A., Vol. II. pp. 194, 195.) This should strictly be represented in equation (2) by an additional term, say $= ik\theta$ (i being a variable, dependent on position on wave), the presence of which would at least technically vitiate the reasoning which follows in the text, though there are reasons for supposing that the errors due to ignoring such term will be to a great extent mutually compensatory. However, i being, *cæteris paribus*, proportional to the wave height, and both this and θ being, *cæteris paribus*, proportional to the general wave steepness, the term vanishes in relative importance as the steepness diminishes, and becomes insignificant in a sufficiently low swell. In point of fact the operation here referred to has never yet been taken account of in any mode of investigation of rolling, not even in that of graphic integration.

also let us suppose that at the particular instant in question the following relation subsist between the three values of θ, and also between the three values of ω,†

$$\theta_A = \theta_C - \theta_B \qquad (3)$$

and—

$$\omega_A = \omega_C - \omega_B; \qquad (4)$$

in other words, that the *absolute* angle and angular speed of A are the same as the angle and speed of C *relatively* to B. Hence, remembering that $\theta' = 0$ for A, and is common to B and C, we get by equation (2) above—

$$\alpha_A = \alpha_C - \alpha_B; \qquad (5)$$

in other words, just as with the angles and angular speeds by hypothesis, so also with the angular accelerations by consequence, the *absolute* values for A are the same as the values for C *relatively* to B.

§ 11. Passing now to the next succeeding instant of time, and considering the changes which will have taken place, during the (supposed infinitesimal) time interval, in the two sides of the above equations (3), (4), and (5), we must have—

Change in θ_A = do. in $(\theta_C - \theta_B)$ (6); [from (4) since change in θ varies as ω].
Change in ω_A = do. in $(\omega_C - \omega_B)$ (7); [from (5) since change in ω varies as α].
Change in α_A = do. in $(\alpha_C - \alpha_B)$ (8); [from (6) since change in α varies as change in θ].

[For any change in θ' during the interval, however arbitrary, must have affected α_B and α_C, *ex hypothesi* alike, and cannot have affected their difference $(\alpha_C - \alpha_B)$.]

§ 12. If, then, we imagine this reasoning to be continued for an indefinite series of such infinitesimal successive intervals, we see that the relations exhibited by equations (3), (4), and (5), cannot fail to *precisely perpetuate themselves.* In other words, whatever the nature of the swell which identically affects ships B and C, the difference between their rolling will always be precisely expressed by the still-water rolling of ship A; or, to use the technical term, the rolling of C must for ever consist of the rolling of A "superposed" upon the rolling of B. Now the rolling of C is, of course, the same as the rolling which B would have itself experienced had it been given the initial angle and angular speed θ_C and ω_C, proper to C, instead of its own initial angle and angular speed θ_B and ω_B; and hence we reach the first important general proposition, which I will formulate as follows :—

§ 13. *Prop. I.—In an isochronous unresisted ship, rolling under the influence of any swell whatever, the difference in the rolling due to any difference in initial angle and angular speed, consists simply in the superposition of a corresponding still-water or* (as it is technically termed) "*free*" *oscillation.*

† In any given ship, whether in still or wave water, at any single instant of time, such as here supposed, if taken without reference to conditions existing at any other instant of time, of course any chosen value of θ may consist with any chosen value of ω.

§ 14. This proposition simplifies the problem immensely. For, whereas a given ship on a given swell may roll in an infinite and, at first sight, inscrutable variety of different ways, according to the particular angle and angular speed with which we may suppose her to start at any particular instant, the proposition shows that the differences between these ways of rolling can only consist in the simple "free" or still-water oscillation, corresponding to the differences in the starting conditions. And it follows that if for any given ship and swell we can somehow determine any one correct solution—namely, a solution correct for any one starting condition—we can thence determine any or every other correct solution—namely, the solutions correct for any or every other starting condition—by simply superposing the corresponding "free" or still-water oscillation on the one primary solution which has been determined.

§ 15. As to this free oscillation, there is no difficulty. It is, in character, a simple, uniform, harmonic oscillation of the natural period of the ship, and its extreme angle (or "amplitude") and phase-time, can be easily determined so that at some particular instant it shall present any given angle and angular speed. The *prima facie* difficulty lies in determining the primary solution, proper to the swell, on which the free oscillation has to be superposed.

§ 16. Up to the present we have made no assumption whatever concerning the nature of the swell, or, to speak more strictly, the variation in θ'; and, if we suppose this variation to be wholly irregular, we can, of course, only determine a correct primary solution for the rolling by graphic integration. But it is worth remark, in passing, that, supposing this once done for any one starting condition, the solution could be made to comprehend the rolling for an indefinite number of other starting conditions, without further graphic integration, by superposition of corresponding free oscillations.

§ 17. If, on the other hand, we now assume (as is assumed for the mathematical integration) that θ' varies harmonically, the required primary solution lies ready to hand. Any correct solution will do, and we can see at once that one correct solution, and that the most simple one, must be the kind of uniform rolling ordinarily termed the simple "forced oscillation." In this, the ship keeps perfect time with the waves, oscillating harmonically in the wave period (say $= T'$), instead of her natural period (say $= T$); the ship angle bearing at every instant the same proportion to the wave-slope, that proportion being such as to so strengthen or weaken the righting forces as to change the period of oscillation from T to T′. In other words, we must always have—

$$\frac{\theta}{\theta - \theta'} = \frac{T'^2}{T^2}; \qquad (9)$$

whence, for characterising the forced oscillation, we get the well-known equation—

$$\Theta = \frac{\Theta'}{1 - \frac{T^2}{T'}}; \qquad (10)$$

where Θ, Θ', are the amplitudes, or extreme angles, of ship and wave-slope respectively.* This simple forced oscillation, then, so defined, may be taken as the primary solution, and the free oscillation, proper to any deviation of the actual starting condition from that of the forced oscillation, must be superposed upon it.

§ 18. But now let us assume that the variation of θ' is not strictly harmonic, but consists merely of some other kind of undulation *strictly recurrent* in period T′. Subject to the latter proviso, it is evident that the vitiation of the strict harmonic character of the undulation will not prevent the subsistence of an analogous uniform forced oscillation, though it will, *pro tanto*, vitiate (in detail) the strict harmonic character of such oscillation. For, such undulation, according to its phase-timing relatively to the ship's oscillation, must operate either to modify the amplitude of the rolling, or to modify the righting forces, and consequently the period of rolling (or both in part); and however irregular (or even unsymmetrical) the undulation may be, there must be some particular phase-relation in which it will modify the period only, and not the amplitude. Also, with this particular phase-relation, there must be some proportion between the amplitudes of ship rolling and wave-slope, with which the effect on the period is precisely to modify it from T to T′. And, given the fulfilment of these conditions, the ship must enter on each fresh undulation with the same angle and angular speed as the preceding; and the rolling, like the undulations, must be strictly recurrent in the period T′. In proportion as the undulation departs from a strictly harmonic character, equation (10), above, will, indeed, become quantitatively inexact; but, were it worth while, it would be easy, by graphic integration, to determine the correction proper to any given character of undulation † and relation of T to T′. Accordingly we may now formulate a second general proposition, as follows :—

§ 19. *Prop. II.—In an isochronous, unresisted ship, rolling under the influence of a swell consisting of any kind of truly recurrent undulations, the rolling will consist of the uniform forced oscillation proper to these undulations, with or without a free oscillation superposed.*

§ 20. Now this proposition merely expresses, in effect, and in ordinary language

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* Here, when T exceeds T′, Θ becomes negative, the meaning being that the ship rolls in the contrary direction to the wave-slopes; and this condition is here conveniently, though with a certain laxity, expressed by contrary signs for the amplitudes. In principle it is more correct to treat the amplitudes as intrinsically positive, and the contrariety of the motion as due to an opposition of *phase;* and for the *resisted* forced oscillation [*vid. inf.* §§ 23, 43] this latter treatment is necessary, since the phase-relation may then be anything between coincidence and opposition; it is therefore adopted below in § 33 and onwards.

† At first sight it seems as if we might in this way determine the exact rolling for truly shaped steep waves; but there would remain the errors (in that case significant in amount) due to ignoring the effect of the varying " hydrostatic tension " (*vid. sup.* footnote *, to § 10).

instead of mathematical symbols, the result of the mathematical integration of the differential equation of unresisted rolling, made rather more general indeed, in that it is not limited to a strictly harmonic swell. And, so far, except for the absence of resistance, we have made no assumption which is not made in M. Bertin's treatment also.

Let us now proceed to take resistance into account.

§ 21. As a first step, let us assume the momentary resistance to be proportional to the momentary angular speed simply ; in other words, let—

$$\text{Angular retardation due to resistance} = r\,\omega,$$

or, algebraically—

$$\text{Angular acceleration due to resistance} = -r\,\omega, \qquad (11)$$

Then the fundamental equation, corresponding to equation (2) above (§ 9), will become—

$$a = -k\,(\theta - \theta') - r\,\omega, \qquad (12)$$

and, if the same train of reasoning* be pursued as was pursued before in equations (3) to (8) (§§ 10, 11), we shall find that Props. I. and II. remain unimpaired, so far as this, viz., that the rolling will still consist of a free oscillation superposed on the forced oscillation ; the only difference being that both the free and the forced oscillation are, each in their own way, modified by the resistance.

§ 22. Thus, (i.), the free oscillation becomes the *resisted* still-water oscillation; in other words, the familiar "extinction diagram."

§ 23. And, (ii.), the resisted forced oscillation differs from the unresisted in the following respects:—(*a*) The phase of the resisted forced oscillation precedes† or follows that of the unresisted, in such a degree that, except for the resistance, each wave would increase the amplitude of the roll by just as much as, except for the wave, the resistance would decrease it.‡ (*b*) In virtue of this alteration of phase-relation, the proportion between the amplitudes of ship rolling and wave-slope, with which the effect

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* Thus, equations (3) and (4) remain unaltered ; then, from equation (12) (text above), and from (3) and (4), we get—

$$a_A = -k\,\theta_A - r\,\omega_A = -k\,(\theta_C - \theta_B) - r\,(\omega_C - \omega_B) = a_C - a_B \quad (5a)$$

From this point the reasoning remains the same as before, being based simply on the conditions of motion exhibited by equations (3), (4), and (5), which are not altered ; bearing in mind, however, that "the still-water rolling of ship A" (§ 12 *sup.*) will now be the *resisted* still-water oscillation, also that in §§ 17—19 the effect of resistance on the conditions of the forced oscillation has to be taken into account.

† *I.e., precedes* when T *exceeds* T′, the unresisted forced oscillation being then contrary to the waves. [*Vid. sup.* § 17, and footnote *, page 8. See also § 43, and footnote *, page 18.]

‡ Or (as it may be described for harmonic waves, and the precise assumption at present made as to the resistance), in such a degree that the momentary wave-slope forces, everywhere differ from the forces required for modifying the period, by the amount required to neutralise the momentary resistance.

on the period is precisely to modify it from T to T′, undergoes some modification. The correct phase-relation and amplitude-relation for fulfilling these conditions may be expressed geometrically or algebraically (in terms of period-relation and resistance) for harmonic waves* ; or, for an undulation of any other specific character, it might be determined by graphic integration, as above noticed (§ 18) for unresisted rolling.

§ 24. But, for an undulation resembling an ordinary wave, it is plain that the result can differ but little quantitatively, and not perceptibly in character, from that for a harmonic wave; and I take this opportunity of observing that in the remainder of this paper, for the sake of simplicity and brevity of statement, I will suppose the waves to be harmonic.

§ 25. In Props. I. and II. of §§ 13 and 19, as thus adapted for resisted rolling, we possess a perfectly comprehensive and very simple mode of solution for rolling in any uniform swell, assuming that the momentary resistance may be taken as simply proportional to the momentary angular speed of the ship. This assumption is doubtless one of those referred to by M. Bertin as "inadmissible," and I quite agree that no solution can be regarded as generally satisfactory unless at least its results can be serviceably adapted to other assumptions.

§ 26. And I must at once admit that the adoption of any other fundamental assumption as to the resistance, technically undercuts the mathematical reasoning whereby Props. I. and II. were deduced from an equation of the form of equation (12) (§ 21); and in such a way that we cannot adapt or restate those propositions so as to be generally correct for any other assumption. All we can do is to use those propositions to give us what we may term a "conventional" result, which will be true for the conventional assumption as to resistance; and then consider how far in such and such cases this result must be either restricted in application, or corrected *ad hoc* by local adjustments of the co-efficients used, with due regard to the supposed true resistance conditions.

§ 27. In exercising this kind of judgment as to the limitations of application of the conventional result, or as to the correction which it may require for the effect of the difference between the conventional assumption concerning resistance and other assumptions commonly employed, we encounter an important preliminary question as to how the resistance may be most properly characterised for this purpose.

§ 28. Any calculus of rolling which is based on an explicit account of the dynamic conditions for successive elementary time-intervals—such, *e.g*, as the treatment which has been so far sketched in this paper; or the method of graphic integration—necessarily requires that the momentary resistance should be characterised as a function

* *Vid. inf.* § 43.

of the momentary angular speed. On the other hand, it is a commonplace of the science of rolling, that if we are concerned, as we are at the stage now reached, only with the gross results in the shape of amplitudes, and not with the minutiæ of motion throughout each swing, it is sufficient, and more convenient, to take account only of the total work expended in resistance in the course of each swing, as witnessed by the "extinction," or loss of amplitude experienced in each swing in still water. The resistance is therefore commonly characterised by this loss of amplitude, in terms of the mean amplitude (or half swing out to out). For our present purposes this may be most conveniently done by such an equation as the following; viz.—

$$\frac{\eta}{\Theta} = \text{E (say)}; \qquad (13)$$

where η = the loss of amplitude per swing,* and Θ = the mean amplitude.

§ 29. Now the definition already given (§§ 21 and 25) of the conventional assumption as to resistance, is that the momentary resistance is proportional simply to the momentary angular speed. So stated, the assumption is indeed not only not generally true, but is probably not even approximately true for other than a few very special cases.† But, characterising the resistance by the extinction, suitably to our present purpose, the conventional assumption is simply that E, in equation (13), is constant for varying Θ; and, so stated, the assumption is serviceably correct for most ships at small amplitudes, and for some up to considerable amplitudes. In any case its error is matter of measurable degree, dependent on the particular ship, and on the amplitude, and range of variation of amplitude, involved in the result, and the consequent degree of variation of E.

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* Often written $= -\frac{d\Theta}{dn}$.

† The frictional resistance due to viscosity of water or other fluids, if no eddying takes place, is proportional to the simple power of the speed, and would therefore be proportional to the simple power of the angular speed of rolling of a given ship. But resistance of this kind only obtains, in water, at very low speeds, which would mean very small angles of roll of ship.

On the other hand, even at considerable angles of roll, the ordinary frictional resistance may cause a rolling resistance proportional to the simple power of the angular speed, in virtue of rapid headway. Under such conditions the motion of the particles over the ship's surface, instead of being in plane of rotation, as in rolling without way on, is nearly in line of axis, and only slightly oblique to it in virtue of the rolling motion. At ordinary steaming speeds this obliquity may be slight enough not to tangibly enhance the speed of the particles along line of path, and in that case the rotary component of the frictional resistance will be proportional to the momentary angle of obliquity, which is in turn proportional to the momentary angular speed of the rolling.

It is conceivable that this principle may apply in some measure also to bilge-keel resistance and the like. It certainly would do so if the keel features were very short in line of motion, like the fin keels of racing yachts.

§ 30. So, if the result, or portion of it with which we are concerned, includes only such a range of variation of amplitude as that the value of E may be taken as serviceably constant within that range, the conventional result, so restricted, will stand good, provided that the assumed resistance has been made to accord with a serviceably correct mean value of E for that range.

§ 31. Otherwise, there is nothing for it but to cut up the solution into sections, such that within each section the result shall comprise only such a range of amplitude as admits of being treated in the manner just suggested, an appropriately different resistance co-efficient being taken in each such section.* This process amounts in effect to a kind of "flying graphic integration" (in that respect resembling M. Bertin's method), the closeness of subdivision of the solution, in other words, the number of steps requisite, being, of course, greatly dependent on the conditions of the particular case, and the degree of accuracy required.

To illustrate this process in detail would overweight the present paper, the purpose of which is rather to show that sufficiently instructive results may be obtained for most cases of ordinary occurrence, without actual recourse to such a process. With this object, we will first examine the form which the naked conventional solution presents in sundry representative cases.

§ 32. In all cases of resisted rolling on a uniform swell, as we have seen, the (conventional) rolling must consist of the resisted still-water oscillation, or extinction diagram,† superposed upon the uniform forced oscillation proper to the supposed swell.

Were we concerned (as just at present we are not) with the quantitative characteristics of that swell, we should have to notice that, relatively to the forced oscillation proper to it, its phase-timing, as well as its extreme wave-slope, depends on the resistance as well as the period-relation of swell and ship (§ 23, *sup.*).‡ At present we need only notice that the forced oscillation considered by itself is merely a uniform or simple harmonic oscillation, having the period T′ of the swell, and some particular amplitude, say, = A. On this uniform oscillation of period T′, has to be superposed the free oscillation of period T, and gradually declining amplitude.

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* Thus, for each section the forced oscillation must conform to the proper resistance co-efficient, and the free oscillation must be such as (when superposed on this) to conform to the values of θ and ω at the conclusion of the preceding section.

† For the purposes of the conventional solution, this extinction diagram must, of course, be conformable to the conventional assumption, *i.e.*, η must be throughout proportional to Θ.

‡ For the definition of the amplitude and phase-relations between forced oscillation and waves, see § 43 below.

§ 33. The effect of this superposition must be, broadly, as follows. At certain points of time, separated by an interval $= n\,\mathrm{T}$—

(where n, taken always positive, $= \pm \frac{\mathrm{T}'}{\mathrm{T} - \mathrm{T}'}$)—

there will be a coincidence of phase between the two component oscillations, and the nett amplitude will be the sum of the two components. And at certain points, midway between these, and therefore themselves also at intervals $= n\,\mathrm{T}$, there will be an opposition of phase, and the nett amplitude will be the difference between the two components. The former series of points, distinguished in Figs. 1 to 16 by the letters D, F, H, J, L, will be approximate * points of maximum nett amplitude; the latter, C, E, G, I, K, of minimum nett amplitude. And, in virtue of the declining amplitude of the superposed free oscillation, the nett amplitudes at the successive maximum points will grow progressively smaller, and those at the successive minimum points progressively greater, until the difference between them becomes undistinguishable, and the rolling merges into the simple uniform forced oscillation.

§ 34. It is easy to see that the results for different conditions must exhibit the following general characteristics, which are illustrated in the diagrams in Figs. 1 to 18.

(*a*) However non-uniform initially, the rolling ultimately falls into the uniform forced oscillation.

(*b*) It does so the sooner, *cæteris paribus*, the higher the resistance.

(*c*) And with the fewer "cycles," or alternations of amplitude of rolling, the more nearly synchronous the swell with the ship.

(*d*) The amplitude of the ultimate uniform rolling is an approximate mean of the alternate maxima and minima of the precedent non-uniform rolling.

(*e*) If the rolling starts from zero, the maximum amplitude falls short of twice the ultimate uniform amplitude.†

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* In virtue of the declining amplitude of the superposed free oscillation, the maximum nett amplitude occurs very slightly before the point of phase-coincidence. At least this is so, taking the local ordinate of the bounding curves as indicative of the local amplitude of the nett oscillation. Whether any actual extreme angle exceeds that ordinate at the point of phase-coincidence, has to do with the precise arithmetical relations between T and T′.

† Except for resistance, the maximum amplitude would $= 2\,\mathrm{A}$, where A (*vide* § 32 *sup.*) is the ultimate uniform amplitude, or amplitude of the forced oscillation.

In the Appendix to Mr. W. Froude's 1861 paper (see Vol. III. p. 47, as already cited), the maximum amplitude for unresisted rolling is given as $= \pm\,\Theta' \frac{q}{q - p}$, $\left(\text{where } \frac{p}{q} = \frac{\mathrm{T}}{\mathrm{T}'}\right)$, which, putting $\Theta' = \mathrm{A}\left(1 - \frac{\mathrm{T}^2}{\mathrm{T}'^2}\right)$ from equation (10) above, (§ 17), becomes $= \mathrm{A}\left(1 + \frac{\mathrm{T}}{\mathrm{T}'}\right)$, instead of $= 2\,\mathrm{A}$. The reason for this

(*f*) And the more so, the higher the resistance;

(*g*) And the more nearly synchronous the swell.

(*h*) In a synchronous swell, the maximum amplitude cannot exceed the ultimate uniform amplitude, unless it does so initially.

§ 35. Now these conclusions are not uninstructive. Nevertheless, their relevance to the practical problem is imperfect, in virtue of the fact that the ideal assumed uniformity of swell does not exist in practice. And hence, in proportion as on the one hand the resistance is small, and any initial non-uniformity of rolling dies hard (so to speak), and, on the other, the non-synchronism is considerable,* and the alternations of amplitude rapid, the continual fresh disturbances due to the non-uniformity of swell, avail effectively to maintain non-uniformity of rolling, in spite of the tendency of resistance to eradicate it. Thus a tendency to continued non-uniformity of rolling is in practice a characteristic feature—and an important one—of rolling in a non-synchronous swell; and we have to consider how best to take due account of this tendency.

§ 36. In this aspect, one form of solution which I have not yet mentioned certainly claims attention.

The non-uniformity of an actual swell is by the best authorities attributed to its supposed composition of several uniform swells of different periods, superposed on one another. Now, by a mere extension of the reasoning by which, in this paper, we arrived at Props. I. and II., as adapted to resistance on our conventional assump-

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discrepancy is that Mr. W. Froude, in the paper referred to, starts with coincidence of phase *at mid-swing*, making the ship start stationary and upright at *wave-trough*, whereas I have here started with coincidence at *extreme angle*, giving the same initial condition of ship at *wave mid-slope*. The former supposition requires free-oscillation starting amplitude $= A\frac{T}{T}$, the latter requires it $= A$ simply.

The difference has to do with certain curiosities (if I may so speak) attaching to the mode of solution, which are, perhaps, of little more than academical interest, and are, at any rate, too intricate to enter on in the present paper. Which of the two suppositions may rightly be regarded as the most relevant—or whether some intermediate one may not be preferable to either—for exhibiting the influence on rolling of different kinds and degrees of non-synchronism, is a debatable question. But for exhibiting the influence of different degrees of resistance under given conditions of non-synchronism, which is, perhaps, the most practically important purpose, the two suppositions seem equally relevant; and I have preferred the one I have used, on the score of the greatly superior simplicity of statement of its results.

* Another, and, as I think, a much more potent reason why both non-synchronism and smallness of resistance increase the sensitiveness of the rolling to any defect of uniformity in the swell, is to be found in the nature of the phase-relations of the forced oscillation. From these, as defined in § 43 below and footnote *, page 18, it is intelligible that when the phase-angle β tends towards $= 0$, or π, as it does in virtue of non-synchronism and low resistance, the slightest disturbance of this angle at once sets free (so to speak) a large component of the wave, to increase or decrease the amplitude of the rolling.

tion, it is easily proved that for a swell so composed, (i.) the nett rolling will consist of the superposition of the systems of rolling proper to the several component swells; (ii.) these systems of rolling will each consist of the appropriate (resisted) forced oscillation, with or without a superposed (resisted) free oscillation; (iii.) the free oscillation terms—or, rather, term, for they may be all grouped into one*—will be extinguished by the resistance; (iv.) the permanent rolling proper to the compound swell will consequently consist simply of the superposition of the (resisted) forced oscillations severally proper to the components of the compound swell.

The relevance of this solution seems undeniable; nor would the computation be very laborious (still confining ourselves to the conventional assumption as to resistance) for a moderate number of component swells. On the other hand, we hardly know enough, as yet, of the composition of an actual swell under various circumstances, to be able to prescribe, so to speak, a sufficiently representative compound wave system, which might serve as a test case for estimating the probable behaviour of different ships, or of a given ship under various conditions.

§ 37. A more serviceable test case, as I think, and certainly one for which the result is more easily computed, is suggested by the common experience that when rolling is far from uniform, the most violent rolls are generally those which shortly follow a moment of approximate quiescence. I propose, therefore, that we should take as our standard criterion of the probable qualities of a ship, in respect of steadiness in a non-synchronous swell, the maximum amplitude which she would attain under the influence of that swell (assumed to be uniform) if started with no roll. Even so, the criterion must be recognised as a somewhat artificial and conventional one, in view of the fact that where several rolls are occupied in reaching the maximum amplitude, as is the case when the non-synchronism is not very great, the deviations from uniformity of the swell during that interval, may have considerable influence on the result.

§ 38. The diagrams in Figs. 1 to 18, Plates XLIX. to LIII., have been computed for the proposed condition of starting with no roll; and the amplitude which it is proposed to take as the criterion amplitude is the first maximum amplitude of these diagrams, which appears in all of them at the points marked D. These diagrams therefore exhibit in a general way, judging by this criterion, how resistance on the one hand and non-synchronism on the other, severally operate to affect the amplitude of rolling, relatively to the wave-slope. The diagrams show, for example, how in a non-synchronous swell, resistance operates to diminish amplitude relatively to extreme wave-slope,†

* The free oscillations, having all the same period (viz., the natural ship period), necessarily sum up into a single oscillation of that period.

† For greater convenience of comparison in some aspects, the diagrams are got out not for a common extreme wave-slope (*i.e.*, Θ'), but for a common value of A, viz., of ultimate uniform amplitude or amplitude of forced oscillation. The severally appropriate values of Θ' are shown on the diagrams.

not so much by diminishing the amplitude of ultimate (uniform) rolling, which indeed in that case it scarcely affects, but chiefly by diminishing the degree in which the maximum amplitude exceeds the ultimate amplitude. They show again how, with given resistance, the effect of non-synchronism to diminish the ultimate amplitude, is in a measure counteracted by its concomitant effects to enhance the excess of the maximum over the ultimate amplitude.

§ 39. It will be readily understood from all that has been said, that this "criterion amplitude" as we have termed it, may be estimated directly by figures without actually constructing any such diagrams (or portions of them) as Figs. 1 to 16.

We start with opposition of phase between the two component oscillations; and in order that at that point the nett amplitude may be *nil*, the two component amplitudes must be equal.* The free oscillation must therefore commence with an amplitude = A, viz., that of the forced oscillation.

The criterion amplitude, which is to be estimated, occurs at the succeeding coincidence of phase,† viz., after an interval $= \frac{n\,T}{2}$, or, in other words, after n single swings of the free oscillation, and at this point the nett amplitude is the sum of the two component amplitudes. We therefore get, for the value of the criterion amplitude, 2 A (or twice the amplitude of the forced oscillation), *less* the aggregate loss by extinction in n swings starting from the amplitude A. Or, algebraically, the criterion amplitude ($= \Theta_c$, say) may be expressed thus—

$$\Theta_c = A\,(1 + e^{-nE}) \qquad (14)\ ‡$$

§ 40. In so far, then, as we are satisfied to regard this so-called "criterion amplitude" as a serviceable criterion of the probable behaviour of the ship for which it is calculated, we possess in the foregoing method and formula all that we require; subject to such error as is incidental to the conventional assumption as to resistance. It remains to consider what this error amounts to, and how far the formula, or its mode of application, may be modified so as to fit other usual assumptions.

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* But see footnote †, to § 34.

† For convenience in computation, the "criterion amplitude" has been conventionally taken at the point of phase-coincidence, although, as noted above (§ 33, footnote, page 305) the precise maximum occurs slightly earlier, and is therefore very slightly greater.

‡ In the extinction diagram (this being for the conventional assumption as to resistance) $\frac{\eta}{\Theta}$, = E, must be throughout constant (*vid. sup.* equation (13), §§ 28, 29). Then, by the mathematical properties of a curve fulfilling this condition—

$$\Theta_0 = e^{mE}\,\Theta_m; \qquad (14\ a)$$

where Θ_0 is the starting amplitude, and Θ_m that after m single swings; ($e = 2{\cdot}72$ approximately). Hence equation (14); since $\Theta_c = A + A\,\frac{\Theta_m}{\Theta_0}$.

To test this, I have worked out, by the process referred to in § 31, the criterion amplitudes for the series of values of $\frac{T}{T_1}$ employed in Figs. 1 to 16, on the assumption that η is proportional to Θ^{2*} (viz., the general assumption advocated by M. Bertin), instead of to Θ simply. The co-efficient has been so taken as to make $E = \frac{1}{10}$ for the amplitude A of the forced oscillation; so that the results, in comparison with those for the conventional assumption as exhibited in Figs. (odd numbers) 1 to 15, may be accounted as computed for the same value of E at the amplitude of the forced oscillation. So computed, as will be seen from the ordinates marked B on the figures in question, the criterion amplitudes for the extinction varying as Θ^2 come materially smaller than those for the conventional assumption.

If, however, in the estimate by the conventional assumption, *e.g.*, by the formula of equation (14), the value of E is taken the same as for the Θ^2 assumption, not at the amplitude of the forced oscillation, but at the maximum or criterion amplitude, we obtain the ordinates marked *b*, which it will be seen agree serviceably with B.

§ 41. This expedient, then, viz., of taking E so as to fit the presumed actual extinction at the criterion amplitude instead of at the forced oscillation amplitude, enables us to obtain by equation (14) a serviceably correct estimate of the criterion amplitude for a ship in which the extinction varies as Θ^2. And on the other hand, to apply the same rule to the case of a ship in which the extinction varied as Θ simply, would not derogate from the correctness of the formula for such a case, simply because in such a case E is the same for all angles. And hence we may pretty confidently infer that with the same rule of application the formula will give an equally correct estimate for any case in which the extinction may be taken to consist of two terms, one varying as Θ simply, and the other as Θ^2.

In all ordinary cases the extinction of ships has been found to be serviceably expressible in this form, whence we may conclude that for all ordinary cases the criterion amplitude may be serviceably estimated by equation (14), if the value of E for use in that equation be derived from the extinction diagram of the ship in question, at the criterion amplitude.

§ 42. To thus determine the amplitude for a specified wave-slope involves, no doubt, a process of trial and error; but, even so, the labour is very little. On the other hand, it is for many purposes equally instructive to conversely determine the wave-slope for a specified amplitude, and this involves no trial and error.

§ 43. For convenience and simplicity of description, I have thus far expressed the nett amplitudes in terms simply of the amplitude A of the forced oscillation, or,

* This makes $E \propto \Theta$ instead of $=$ const.

as I have also termed it, the ultimate uniform amplitude; and it remains to define the relation of this amplitude A, to Θ', the extreme wave-slope. The conditions governing this relation were correctly investigated in Professor Rankine's paper "On the Action of Waves upon a Ship's Keel" (Vol. V. p. 20), and the late Mr. W. Froude's paper "On the Practical Limits of the Rolling of a Ship in a Seaway" (Vol. VI. p. 175), and their *rationale* has been sketched above in § 23.

The relation is, to my mind, most intelligibly and conveniently shown by diagram, as in Fig. 19, Plate LIII., where the relative values of A and Θ' are shown by the relative lengths of the appropriate lines; also, the relative lengths of the line marked Θ', and of the two sides of the triangle to which that line is the hypotenuse, show the amplitude-relation of the wave to its two components, which operate respectively to overcome the resistance and to force the period. Again, the inclination of that hypotenuse, shown as the angle β, expresses the phase-relation between the wave and the rolling, which provides for that distribution of the total wave effect; the ratio $\frac{\beta}{2\pi}$ expressing the fraction of T′ by which the extreme wave-slope *precedes* the extreme angle of ship in the same direction.*

The symbol η_A in the figure, is the value which the extinction η has for the amplitude A when the extinction takes place in the period T′. For the purposes of the conventional solution (which assumes resistance proportional to *angular speed*), the extinction must be taken as, for given amplitude, inversely proportional to the period, which gives—

$$\eta_A = EA\frac{T}{T'} \qquad (15)$$

where E is the value of $\frac{\eta}{\Theta}$ for amplitude = A and oscillation in period T.†

The most convenient algebraical expressions for the amplitude and phase-relations of A and Θ' depend on the form in which the problem may present itself; but the

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* For no resistance—*i.e.*, when $\frac{2}{\pi}\eta_A = 0$, $\beta = 0$ or π, according as T is less or greater than T′; the variation of β with resistance thus accords with the description of the effect of resistance on phase-relation in § 23 above.

† The true dependence of extinction on period is a matter of some uncertainty. If the resistance were truly expressible as proportional to ω^x, say (where ω is the angular speed), then for a change of period from T to T′ by wave forcing (since this change of period involves no change in "W M" or inertia of ship) η must be multiplied by $\left(\frac{T}{T'}\right)^x$. And this probably holds good for extinction due to frictional resistance of hull surface and the like; but as far as wave-making extinction is concerned, although such extinction is equivalent to an extinction due to resistance proportionate to ω, in respect to its dependence upon amplitude, it does not in the least follow that it is so likewise in respect to its dependence upon period.

following formulæ may be written down as arising directly out of the geometrical relations indicated in the figure :—

$$\Theta' = \sqrt{A^2\left(1 - \frac{T^2}{T'^2}\right)^2 + \left(\frac{2}{\pi}\eta_A\right)^2}, \qquad (16)$$

$$\text{Cotan}\,\beta = \left[\frac{\pi}{2\,\eta_A}.\,A\left(1 - \frac{T^2}{T'^2}\right)\right]. \qquad (17)$$

§ 44. I append [Appendix I.] an example of the mode of estimating the relation of wave-slope and "criterion amplitude" for a particular case; also [Appendix II.] a Table showing a series of results computed for a few actual ships among those for which the extinction co-efficients have been published; also [Appendix III.] some comments on the remarks in reference to rolling extinction in general, which appear in the latter part of M. Bertin's 1895 paper [Paris Meeting].

APPENDIX I.

Example of Mode of Computing Relation between Criterion Amplitude and Wave-slope.

H.M.S. "Revenge."—*Deep draught with bilge keels*; natural period, say, = 16·0 sec.; wave-period, say, = 13·0 sec. *Find wave-slope* (Θ') *corresponding to criterion amplitude* ($= \Theta_c$) of 12·0°.

(N.B.—In this working all angles are to be understood to be in degree units.)

(i.) In *re* period; $\frac{T}{T'} = 1{\cdot}23$; hence n (see text, § 33) $= 4{\cdot}\dot{3}$; $1 - \frac{T^2}{T'^2} = -\,{\cdot}515$.

(ii.) In *re* extinction; $\eta, = -\frac{d\,\Theta}{d\,n}, = {\cdot}065\,\Theta + {\cdot}017\,\Theta^2$* (or, as it is commonly described, $a =$ ·065, $b =$ ·017); hence, η for Θ_c ($= \eta_c$, say) $= {\cdot}78° + 2{\cdot}45° = 3{\cdot}23°$; giving E, $= \frac{\eta_c}{\Theta_c}$, (see text, § 41), $=$ ·269; and nE $= 1{\cdot}17$.

(Or, less obviously, but more simply, $E = a + b\,\Theta_c, = {\cdot}065 + {\cdot}204 = {\cdot}269$).

Then $A = \frac{\Theta_c}{1 + e^{-nE}}$ (see eqn. (14), § 39) $= \frac{12{\cdot}0}{1{\cdot}311} = 9{\cdot}15°$.

And η, for amplitude A and period T', $= \eta_A, = E\,A\,\frac{T}{T'}$ (see eqn. (15), § 43), $= 3{\cdot}03°$.

Then $\Theta', = \sqrt{A^2\left(1 - \frac{T^2}{T'^2}\right)^2 + \left(\frac{2}{\pi}\eta_A\right)^2}$ (see eqn. (16), § 43) $= \sqrt{22{\cdot}2 + 3{\cdot}7} = 5{\cdot}09°$.

For the converse problem of determining the criterion amplitude for a given wave-slope, a process of trial and error is necessary; or a curve may be plotted showing Θ' to a base of Θ_c, and the values of Θ_c corresponding to any given values of Θ' read off from the curve.

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* Trans. I.N.A., Vol. XXXVI. p. 142.

APPENDIX II.

Table of Results Computed for Actual Ships.

(1) Wave-slopes (Θ'), and ultimate uniform amplitudes (A), for a common criterion amplitude (Θ_c) of 10·0°.

	$\frac{T}{T'} = 1{\cdot}3$ $n = 3{\cdot}\dot{3}$		$\frac{T}{T'} = 1{\cdot}2$ $n = 5$		$\frac{T}{T'} = 1{\cdot}1$ $n = 10$		$\frac{T}{T'} = 1{\cdot}0$ $n = \infty$	
	Θ'	A	Θ'	A	Θ'	A	Θ'	A
	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	
Inconstant	3·96	5·7	2·70	6·05	1·53	7·05	0·55	10·0° throughout.
Sultan...	3·69	5·35	2·44	5·55	1·29	6·05	0·28	
Revenge (deep draught) no bilge keels	3·66	5·3	2·41	5·45	1·25	5·9	0·24	
Revenge (ditto) with bilge keels ...	4·91	6·85	3·63	7·65	2·44	9·15	1·50	
Devastation	4·82	6·75	3·55	7·5	2·36	9·0	1·41	

(2) Wave-slopes (Θ'), and ultimate uniform amplitudes (A), for a common criterion amplitude (Θ_c), of 20·0°.

	$\frac{T}{T'} = 1{\cdot}3$ $n = 3{\cdot}\dot{3}$		$\frac{T}{T'} = 1{\cdot}2$ $n = 5$		$\frac{T}{T'} = 1{\cdot}1$ $n = 10$		$\frac{T}{T'} = 1{\cdot}0$ $n = \infty$	
	Θ'	A	Θ'	A	Θ'	A	Θ'	A
	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	
Inconstant	8·55	12·25	6·0	13·3	3·68	15·95	2·74	20·0° throughout.
Sultan...	7·6	11·0	5·08	11·5	2·76	12·9	1·20	
Revenge (deep draught) no bilge keels	7·6	11·0	5·11	11·55	2·79	13·0	1·25	
Revenge (ditto) with bilge keels ...	12·2	15·9	9·5	17·65	7·0	19·65	8·1	
Devastation	11·7	15·5	9·1	17·3	6·5	19·5	7·45	

(3) Criterion amplitudes (Θ_c), and ultimate uniform amplitudes (A), for a common wave-slope (Θ'), of 3·0°.

	$\frac{T}{T'} = 1{\cdot}3$ $n = 3{\cdot}3$		$\frac{T}{T'} = 1{\cdot}2$ $n = 5$		$\frac{T}{T'} = 1{\cdot}1$ $n = 10$		$\frac{T}{T'} = 1{\cdot}0$ $n = \infty$	
	Θ_c	A	Θ_c	A	Θ_c	A	Θ_c	A
	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	
Inconstant	7·7	4·33	11·0	6·7	17·1	13·2	27·2	Same as Θ_c
Sultan...	8·15	4·34	12·15	6·8	21·5	14·0	45·9	
Revenge (deep draught, no bilge keels)	8·25	4·35	12·25	6·8	21·2	13·9	41·1	
Revenge (ditto) with bilge keels ...	6·6	4·24	8·6	6·4	11·55	10·8	14·85	
Devastation	6·65	4·26	8·75	6·4	11·85	10·9	15·5	

These Tables have been worked out only for values of $\frac{T}{T'}$ greater than unity, this being the condition of most frequent occurrence with large ships. For values of $\frac{T}{T'}$ less than unity, the results will be nearly the same as in the Tables for the same values of n; the (small) difference lying in the ratio of A to Θ', and not at all in the ratio of Θ_c to A.*

The values of A have been shown in the Tables, in order to illustrate the circumstance (see text, § 38) that when non-synchronism is considerable, the effect of resistance to diminish maximum amplitude (Θ_c) relatively to wave-slope, consists in diminution of ratio of maximum (Θ_c) to ultimate amplitude (A), rather than in diminution of ratio of the latter to wave-slope.

In computing the Tables, the resistance co-efficients in the following formula,

$\eta_c, = -\frac{d\,\Theta}{d\,n}$ for angle Θ_c, $= a\,\Theta_c + b\,\Theta_c^2$ (angles taken in degree units), have been taken as follow:—

Inconstant ... ... $a = {\cdot}035$; $b = {\cdot}0051$ (see Trans. I.N.A., Vol. XXXVI. p. 141).
Sultan ... ... $a = {\cdot}0267$; $b = {\cdot}00166$ (*Ibid.*).
Revenge (deep draught), no bilge keels $a = {\cdot}0123$; $b = {\cdot}0025$ (*Ibid.*).
Revenge (do.), with bilge keels $a = {\cdot}065$; $b = {\cdot}017$ (*Ibid.* p. 142).
Devastation ... ... $a = {\cdot}072$; $b = {\cdot}015$ (Trans. I.N.A., Vol. XXIV. p. 174).

APPENDIX III.

Comments on the Remarks Concerning Extinction of Rolling in M. Bertin's 1895 Paper.

(1) Wave-Making Extinction.

The supposition that wave-making might be a source of extinction, was, I believe, first put forward publicly, in an article in *Naval Science* for October, 1872, by my father, the late Mr. W. Froude. I confess I cannot follow the purport of M. Bertin's remarks on the subject. He speaks of the vessel,

* That is, for constant Θ_c. For constant Θ', the difference in E arising out of any difference in Θ_c, will *pro tanto* affect the ratio of Θ_c to A.

during the extinction experiment in still water, being "surrounded with water put into oscillation *during the first period*" (my italics). But neither the wave created "during the first period," nor those successively created during each subsequent period, to the creation of which a part of the extinction during each such period is severally due, remain "surrounding" the vessel so as to influence her subsequent movements. Each wave, as created, travels away from the ship at the speed proper to its period, and cannot influence her again, unless it be reflected back from the shore.

Again, M. Bertin's reference to the experiments on the *Revenge* under way, suggest that he regards the wave-making resistance to rolling as a derived effect of the wave-making due to headway. But the wave-making due to rolling, investigated by Mr. W. Froude, has nothing to do with the wave-making due to headway, and would seem to be theoretically independent of headway.

(2) Viscosity Extinction.

M. Bertin appears to treat resistance due to viscosity as being independent of speed of relative motion, and the extinction due to this cause as therefore independent of amplitude of rolling. But, so far as my reading extends, viscosity resistance has always been held, and is still held, to be proportional to the simple power of the relative speed. I am not aware of any species of external fluid resistance to rolling which can be independent of amplitude, except the capillary resistance at the surface. This latter has been found very sensible in rolling experiments made on moderate-sized models, but must be quite insensible in the case of a ship.

(3) Water Chamber Extinction.

In the experiments on the model of the water chamber of H.M.S. *Edinburgh* this was found to be, for certain conditions, and above a certain very moderate amplitude, independent of amplitude; whence M. Bertin infers (see preceding heading) that the resistance was of the nature of viscosity. Had M. Bertin had the opportunity of observing the behaviour of the water in the model, he could not have failed to recognise that the phenomenon had no more connection with viscosity than has that of the breaking of sea waves on the shore. The true explanation of the constancy of the extinction above a certain amplitude, is that the extinction is due to the reciprocating displacement, transversely to the ship, of the C.G. of the contained water, and that at the amplitude in question this displacement attains the maximum amount consistent with the dimensions of the chamber.

(4) Extinction Expressed by Two or More Terms.

The expression of the extinction by two terms, one proportional to the simple power and the other to the square of the amplitude, was practised by Mr. W. Froude so long ago as 1871; and the expedient has since been in common use in this country. M. Bertin (equation 20 of 1895 paper) puts forward such a formula with approval, but appears to prefer one involving also a term independent of amplitude. For reasons given under heading (2) above, I consider there is no *à priori* justification for the presence of such a term unless when a water chamber may be employed. And, so far as my own experience extends, the results of extinction experiments on ships, may be quite satisfactorily expressed by the two terms first mentioned, without the introduction of one independent of amplitude. An exception, indeed, must be made of the case of the *Revenge* with bilge keels (see Trans. I.N.A., Vol. XXXVI., Plates XII. and XIII., curves E and F) where undoubtedly, for the range of experiment, the agreement of the mathematical expression with the observed extinction might be improved by the introduction of a constant term *with a negative sign*. But an expression so obtained must be accounted purely empirical.

DISCUSSION.

Sir William White, K.C.B., LL.D., F.R.S. (Vice-President): My Lord and Gentlemen, we must all be glad that M. Bertin, by writing his paper, has led Mr. Froude to finish the work he has had in hand for ten years, and to give us the results. Although Mr. Froude differs strongly from M. Bertin on many points of procedure, I am confident that M. Bertin will take the criticisms in the same spirit in which they are made, and will feel that nothing has been said which could not with propriety be said in regard to what, after all, is a matter of scientific investigation. I can say this confidently, because I had the pleasure of talking with M. Bertin on the matter in Paris after he had received from Mr. Froude an early copy of his paper; and, further, I have M. Bertin's authority to say that, he very much regrets that an official engagement prevents him being here to take part in the discussion, but he hopes to be allowed (as the custom of the Institution permits him to do) to contribute a written note to the discussion dealing with the allusions that are made to his investigations. In accordance with our procedure that communication can be made on the understanding that the author of the paper is entitled to see what is said, and to make such rejoinder as he may desire, always subject to the approval of the Council. We may hope, therefore, that to-day's chapter of this important and interesting subject will be followed by another. We may hope also that while M. Bertin will thus deal with certain points raised by Mr. Froude, we shall have, later on, another paper from M. Bertin continuing the subject, and defending that procedure which, I understand, he still prefers. I have had the pleasure of reading this paper most carefully, and I venture to express the opinion that it is the most important piece of work on the subject which has been done during the last twenty or twenty-five years. This subject is one with which I may claim some familiarity—it has been a subject of study on my part for more than thirty years, since I was a student at the School of Naval Architecture, where I and my fellow students, as young Naval architects, were nurtured on the papers of the late Mr. Froude and Professor Rankine dealing with this subject. Ever since that time the matter has had for me the greatest attraction. I have ventured to dip into books, which are now more than a century and a half old, dealing with this matter, and I have read up nearly everything that has been published in the interval. So that, in expressing my favourable opinion of Mr. R. E. Froude's work, I do it with the full knowledge of what has been written, and I am sure that when this paper comes to be studied by members of the Institution the opinion that I have ventured to express will be fully endorsed. The paper is not one that permits of discussion offhand—it is not possible—it is a paper to be studied. But there are great features in this paper which must have been obvious to the meeting as Mr. Froude has given his brief description. Mr. Froude has brought forward a method of mathematical investigation and graphic representation that is most charming and interesting. He has been careful to point out that, in order to bring mathematics to bear on this subject certain conventions and assumptions must be made, and the work must proceed in accordance therewith. He has also been most careful to state that, under the actual conditions of a seaway there are such an infinite variety of circumstances occurring that no mathematical theory can completely represent them. It is, in fact, difficult to say what is the worst thing that can happen to a ship at sea. I am sure that every Naval officer present will endorse that view, and will say that the seas which ships have actually to meet do not correspond to those rounded and graceful and uniform shapes which are shown on mathematical diagrams. It was once my fortune to spend some days on what is called a "line of observation" somewhere between Ushant and Falmouth with the wind blowing a gale all the time,

but veering in its direction. I learnt more about what the sea could do on that occasion than I ever learnt before, and I now have much less belief in the representation by a single trochoidal form of the shapes which water in motion can assume. I saw on that occasion masses of water which looked extremely like pyramids, and these had a nasty habit of tumbling over on the deck. Of course, we know that these forms may be obtained by the superposition of series of trochoidal forms of different dimensions, speeds, and directions of advance, but the possible combinations are infinite in number. While that is true, Mr. Froude fully and clearly expresses the limitations within which it is possible to reduce the mathematical treatment of this most difficult subject. The paper has another most distinctive feature. It summarises, classifies, and arranges most clearly, practically all the work that has been previously done, and then goes much beyond. It attempts, and, I think, attempts with success, under the conditions laid down, to put into a practical shape, and into a shape which will be readily understood, the results that are obtained, and to show how non-periodic rolling, which is certainly the usual condition, may be dealt with mathematically, not merely on the theory of unresisted rolling, but for resisted rolling, when the results of still-water experiments on actual ships can be brought into the account. The effect of fluid resistance in modifying rolling must be counted up and due allowance made for it; and Mr. Froude's method makes a remarkable advance in a simple form. Mr. Froude is careful to say that graphic integration—a process which was independently originated by the late Mr. Froude, whoever else may have independently worked on the same lines—based upon the results of actual rolling experiments is the only way of dealing with this subject thoroughly. But, on the other hand, some great lines of investigation on certain conventions and conditions may be of immense value in dealing with actual ships; and the diagrams which Mr. Froude has put upon the wall show, from such a study as he has made, the most interesting deductions of a general nature may be drawn. Before sitting down, I may refer to one point with which I have some personal interest; it is a footnote on page 297. Mr. Froude's footnotes are eminently suggestive and interesting. I think the paper would be worth printing for its footnotes alone; for the little asides which will be found in these footnotes are of the greatest value and interest to everyone who reads the paper carefully. Mr. Froude says, at the end of that footnote, "In point of fact the operation here referred to has never yet been taken account of in any mode of investigation of rolling, not even in that of graphic integration." Now, as a matter of fact, in my paper on the rolling of sailing ships, which I read before the Institution in 1881, after the loss of the *Atalanta*, allowance was made for the heaving motion. This must be done when one is dealing with an external force (such as wind pressure) which has a capsizing effect on the ship. In the graphic integrations in that paper due allowance for heaving was made. All ordinary investigations of rolling proceed independently of the action of wind on the sails or hull, and I perfectly agree with Mr. Froude that, under the assumption the correction is not one to which any great importance need be attached. There is another very interesting thing on page 299. The equation at the bottom of that page is one which every student of the subject is perfectly familiar with. A great many years ago I discovered a fact in reading some old French books, and published the discovery in "Naval Science," viz., that the formula which had been arrived at by the late Mr. Froude from his independent investigations had been arrived at by Daniel Bernoulli, and communicated to the French Academy of Science about 1750 or 1760. That, my Lord, is all I wish to say.

Mr. J. I. Thornycroft, F.R.S. (Vice-President): My Lord, I would like to make one or two remarks. Sir William White has said so much, and said it so well, in praise of this most admirable paper, that I feel I have nothing to say on the subject; but I do feel that what Sir William White has

said about the combination of observation and integration is a matter from which we ought, not only to draw a moral, but that we ought to ask those who have an opportunity of observing what takes place at sea to record it, as far as possible in a manner which would be of use to enable Mr. Froude to give us a notion of what would happen in the more complicated wave systems which occur. There is only one objection I would make to what Sir William White has said. He has led us to believe, to some extent I am afraid, that the kind of motion that can be dealt with by the process that Mr. Froude has brought before us is limited to the very simple motion of a line of sines; but it has been pointed out by Lord Kelvin that, by combining or superimposing a number of simple curves of sines you can get waves of a most awkward character, and if you simply combine in a certain phase at right angles two similar systems of waves you can produce the pyramids which look so very awkward at sea and which have such very steep places; and by combining not more than four systems of waves you can really build up waves of a most angry character. I believe that what Mr. Froude has brought before us here can deal with even this case. But I agree with Sir William White perfectly in this, that what will happen at sea we must take as the great undivulged, or something of that sort, and when we have done our best there must be much left still which will be most uncertain.

Professor J. H. Biles (Member of Council): My Lord, I am afraid I have very little to say on this paper, because, as Sir William White has said, it is a paper that does not admit of discussion. I hope to be allowed to express my own personal gratitude to Mr. Froude for putting before us this difficult subject in such a clear and easy method for appreciation. I think the method Mr. Froude has adopted, and his general method of investigation, is very strikingly different to the method that is adopted in the general mathematical solution of such questions. I am hardly at liberty to say what the next paper is; but, when you hear it read, I think you will appreciate what I say now, that Mr. Froude seems always to approach a question from the point of view of attempting to make anyone who is not familiar with mathematics understand it. It is very much easier for those who do understand mathematics well to take the mathematics, and obtain a solution in the best way they can by the help of those mathematics; but, unfortunately, the interpretation and the interest then is confined to a very small number of people. But, while Mr. Froude's reading, to highly trained mathematicians, is not perhaps so easy as the mathematics would be, I think, to the large majority of people, the reading and understanding, which he puts into the matter, are of much greater value than if he were to adopt the methods of Continental mathematicians, and express things in a more mathematical way, without the large field of listeners that he has at present. I think this paper opens up quite another field for investigation. I think we had perhaps got into the habit of thinking we knew all about rolling, and that the matter was not worth much consideration. Those who go to sea and take an interest in this subject have opportunities of observing accurately the rolling of ships at times, and I happened last summer to spend a great deal of time at sea, and I amused myself by recording the angle of roll by a batten instrument. I was very much interested and puzzled to observe the great variation in the rolling—the different phases of it. The phases were not regular; the oscillations were not regular; and it is impossible to describe these things, but one thing that I noticed may be of interest on this question: that from the observation of the rolling of the ship, I determined that, at one time, that ship had a considerable negative metacentric height—I mean several inches—and was rolling freely under the action of the waves in quite an easy manner. The period was an exceedingly long period—I do not know that I ever heard of such a one —I am perfectly sure the period of the double roll was thirty seconds, in a ship of about 10,000 tons displacement; and the only thing, I think, that could have caused the period to have been so

long was the excessively small amount of metacentric height, and also the negative character of it, of which I was sure, because the vessel would roll on one side for a considerable number of oscillations, and presently, when the oscillation became large enough to take her over the other side, then she would tumble over there and oscillate a little on that side, but not much, because the wind was on that side, and she was steadily held down, and oscillated to some point several degrees from the vertical. It may be some consolation to Mr. Martell that that ship was perfectly safe at that time—she is a ship which Mr. Martell is quite familiar with—and I think it is of interest to state that it is possible for a ship to have negative metacentric height, and roll quite comfortably at sea and be safe.

Mr. Thornycroft: Negative in the vertical position only?

Professor Biles: Yes; what we call the ordinary upright metacentric height—the distance between the upright metacentric height and the centre of gravity.

Mr. R. E. Froude, F.R.S. (Associate Member of Council): I have very few remarks to make in reply, but I should like to thank all the speakers, and particularly Sir William White, for the exceedingly flattering terms in which they have spoken. I think I really have no remarks to make except one with regard to Professor Biles, which I might touch upon. He complimented me on the way in which I endeavoured, in all these papers, to put things so that they should be intelligible to people who do not understand mathematics. There is a simple explanation of that, which is, that I have to put them so that I can understand them myself. I do not claim to be a master of mathematics in a technical form. My power of doing mathematics is somewhat like what Artemus Ward said, with regard to his father's power of reading: "He reads well, but, as he spells every word, I may say he reads slow." I certainly would not wish for a moment to underrate the value of technical mathematics, such as we have a fine exhibition of in the next paper, because there is no doubt that persons who can use technical mathematics well can arrive at results in a surprisingly quick time, although those results may be afterwards capable of being understood without technical mathematics. As to Sir William White's remarks, I am ashamed to say that I did not take the trouble of looking at his paper on "The Rolling of Sailing Ships," so that I missed the point that he mentions. However, I intended my statement to be taken quite generally, and generally I believe it is true that, in the ordinary use of graphic integration the hydrostatic tension is not taken into account. With regard to Bernoulli's expression of the equation for the forced oscillation, I had noticed that that was referred to in Dr. Woolley's paper at the first session of the Institution. As to Sir William White's remarks with regard to the confused nature of the seas, and their departure from the comfortably rounded forms that are assumed in the mathematics, those departures are due, no doubt, as Mr. Thornycroft has said, to the superposition of small waves on the top of big ones. Now, those peaks and other characteristic features of a confused sea are features of the very greatest importance in reference to the behaviour of ships. That I do not wish to deny, but I contend that they affect the behaviour of ships mainly in a particular way. In the main, I think we may say this: that the movements of the ship, and the momentary attitudes she will assume, are settled by those underlying larger waves, which are assumed by mathematical investigation; and that these superimposed features settle the effect which the water will have upon the ship in the attitudes which she so assumes.

The President (the Right Hon. the Earl of Hopetoun, G.C.M.G.): Gentlemen, I take it it is your pleasure that a vote of thanks be accorded to Mr. Froude for the very interesting contribution

that he has made to the proceedings. I can only say that, as far as I am myself concerned I shall look upon the rolling of ships from an entirely different point of view in the future to that in which I have looked upon it in the past. Hitherto I have always found the rolling of ships most unconventional and very apt to upset my own centre of gravity. In future I shall endeavour to take a different view of the matter.

COMMUNICATION RECEIVED FROM M. E. BERTIN (HON. MEMBER).

I am happy that the addition which I gave in 1894 and 1895 to my old studies should have produced the important paper which has been read by Mr. R. E. Froude. There will certainly result therefrom some further practical progress which will be of importance in the theory of ships.

At the end of his paper, in Appendix III., Mr. Froude points out to me some particulars in my work which appeared obscure to him. I can supply the necessary explanations in a few words.

I will take, for greater convenience, the four observations, 1, 2, 3, and 4, of Appendix III. in the inverse order in which they are presented.

(4° and 3°).—Extinction Expressed by Two or More Terms.

Water Chamber Extinction.

The study of the effects produced by water chambers, especially in the case of the *Edinburgh*, has led me to arrive at results different to those indicated by Mr. Froude; as we have here only to do with questions of fact, verification should be easy.

First of all, it is well to remark that the reciprocating displacement of the centre of gravity of the water contained in the chamber modifies the work of the couple of stability, and not the work of the resistances which produces the extinction of the rolling. The work of gravity is always *nil* between two journeys to the position of equilibrium. We must consequently seek elsewhere for the explanation of the extinction of rolling by the water in the water chambers.

Taking the curves of extinction relating to the *Edinburgh* when provided with different water chambers, filled to the level which corresponds with the maximum extinction, I found that these curves, at a very small distance from the origin, could be represented with surprising exactness by the following equation of two terms :—

$$\Delta\theta = A + N\theta^2 \qquad (1)$$

Moreover, N is the same for all the curves, while A varies according to the water chambers employed. The table on next page gives the figures corresponding to five curves of extinction.

The effect of the water chamber is thus to increase the value of the constant term A in formula (1); it gives to this term a quite unforeseen importance.

(2°).—Viscosity Extinction.

The term A in expression (1) represents, in fact, certain resistances, the work of which is proportional to the semi-amplitude θ of the roll, and is independent of the angular velocity of the ship. These are precisely the resistances which I have expressed by the word viscosity.

	Co-efficient. N.	Co-efficient. A.	Weight of water. p. Tons.	Ratio. $\frac{A}{p}$
No cistern	0·018	0·08	0·0	...
A cistern of 13·10 metres...	0·019	0·47	43·0	0·011
,, ,, 15·70 ,, ...	0·019	1·26	78·8	0·016
,, ,, 20·42 ,, ...	0·019	2·08	135·2	0·015
Two cisterns of 20·42 metres	0·019	3·56	270·4	0·013
			Mean	0·014

Let a resisting work T_1 be expressed by the equation—

$$T_1 = K\,\theta, \qquad (2)$$

and let us calculate the reduction of amplitude $\theta_{n+1} - \theta_n$, which it will produce between two successive rolls.

The work of the couple of stability, during the roll from one side to the other, $\theta_n + \theta_{n+1}$ is—

$$\frac{1}{2} P\,(\rho - a)\,(\theta_n^2 - \theta_{n+1}^2) = \frac{1}{2} P\,(\rho - a)\,(\theta_n + \theta_{n+1})\,\Delta\,\theta. \qquad (3)$$

where P is the displacement of the vessel and $\rho - a$ is the metacentric height.

The work of resistance T_1 is—

$$K\,\theta_n + K\,\theta_{n+1} = 2\,K\,\frac{\theta_n + \theta_{n+1}}{2}. \qquad (4)$$

From the equality between these two works we obtain—

$$\Delta\,\theta = \frac{2\,K}{P\,(\rho - a)}. \qquad (5)$$

We thus fall upon a constant term A, and we have even a theoretical expression for this term.

We could even, while giving to K the value 0·014 p, indicated by the experiments with the *Edinburgh*, calculate the numerical applications for all possible cases. This would be going too far. It is wiser to limit ourselves, for the present, to what precedes; but we may, at any rate, make the remark that, the interior work of resistance, independently of the speed with which the water is deformed, is, according to the approximate data furnished by the water chambers of the *Edinburgh*, much more important than it could have been supposed to be hitherto.

It can be understood that a vessel without headway, without water chambers, carries with it externally, when it rolls, a certain quantity of water, which is deformed while remaining in contact with the hull; from this results the resisting work of viscosity, according to the definition adopted, and hence, also, the term A, in the algebraical expression for $\Delta\,\theta$, indicated by the ordinary curves of extinction of vessels without water chambers.

(1°).—Wave-making Extinction.

It is possible that on this point, especially, there may be a misunderstanding resulting from the multiple uses of the word period in French. In the experiments with artificial rollings I have called the first period of the experiment the commencement of the experiment, and not the first very feeble roll of period 2 T_n.

A rolling ship produces two waves in opposite directions, one to port and the other to starboard, in which the molecules have the well-known orbital motion. If the ship were sharply withdrawn from the water the orbital movement would diminish very rapidly, but it would not cease instantaneously; the place vacated by the ship would be occupied by small chopping waves, from which would emanate the two waves reduced.

The inertia of the water which causes it to preserve its orbital movement, at the spot, is a cause of the reduction of the resistance of the ship to rolling. I verified this a long time ago when causing *La Navette* to roll at first when stationary, and then when under headway, at different speeds; I found that the resistance of the rolling increased with the speed.

Thus the resistance of the water to rolling has a wave-making power on the water. The effect of this wave-making power on the hull is, moreover, to diminish the resistance rather than to increase it. The only comparison which I made, between the resistance to forward motion and the resistance to rolling, bears on the effect of wave making.

The resistance to forward motion, like the resistance to rolling, though for another reason, is wave making. The water pushed away by the ship takes the movement which permits it to make way for the hull with the least possible resisting work; the movement is, to a very great extent, a movement of waves, and hence comes the wave-making power of the resistance.

If, for any reason, the creation of waves were impossible, the water would undergo internal deformation more or less analogous to that for which we found so great a resisting work in the water chambers of the *Edinburgh*. In every case the resisting work would be increased. Thus the wave-making power appears here also to be a cause of diminution and not of increase of resistance.

If I remember rightly, it has been advanced, in support of the supposition that the wave-making power is a resistance to the progress of the ship, that fishes experience a greater resistance in moving when they are near the surface of the water, in consequence of the system of waves which they raise and carry along with them; the fishes would be sensible of this resistance, and would carefully avoid the neighbourhood of the surface. In the case of the opposite supposition, the habit of fishes of keeping far from the surface should be due to other causes. Experiments made with torpedoes indicate that the resistance diminishes near the surface.

Antiquity of the Different Methods of Analysing Rolling.

In conclusion, I should like to say a few words on the antiquity of the different methods of analysing rolling.

I do not know the exact age of the modern method, because M. Reech rarely published his works. I passed my examinations as an engineer pupil on the mathematical integration which

constitutes the modern method. Before my time, many other pupils of M. Reech, both Frenchmen and foreigners, did the same thing. M. Reech was professor for forty years. On many other questions M. Reech was in advance of his time; in fact, in my opinion, he was even in advance of the present time, because we have hardly, even to-day, all the elements necessary for solving the question mathematically in all its complexity, in spite of the notable progress made since 1861, and which is due to the two eminent *savants* of the name of Froude, at Torquay, and afterwards at Haslar.

As to the ancient method of proceeding, it was originated exactly in the year 1866, an epoch at which I found myself face to face with the problem of the maximum roll for a particular ship, which it was hesitated to allow to proceed to sea. I was not aware of the work of Mr. W. Froude, but certainly the empirical formulæ of D. Bernoulli, and the integral of M. Reech did not give me the solution. I found no better course than to trace experimentally a curve of moments of stability for given angles of inclination, and, on the same occasion, I drew for the first time the curve of extinction of rolling.

I would not, however, affirm that the ancient method reaches back to a more recent epoch than the modern one. That appears to me to be true only if we limit our inquiries to the work of the present century.

The exclusive use made of mathematical formulæ (which represent very imperfectly the rolling of a ship) for the purpose of establishing the laws of naval architecture, is not the work of M. Reech alone, nor yet of Mr. W. Froude in his first memoir; this use reaches back really to the primitive formula employed in the works of Daniel Bernoulli. The predecessors of Daniel Bernoulli, on the contrary, who were very distinguished practical men, rather than practised mathematicians, laid the foundations of naval architecture on their knowledge of the sea and of the qualities of ships; it is really the example of these latter which was followed, when experience with artificial rolling, including the drawing of the curve of extinction, was created, and when the graphic tracing of the movements of the sea with the help of the "oscillograph" was undertaken.

The true dates of the two systems, under the names by which they are designated by Mr. Froude, being thus fixed, the reasons which make in favour of the ancient system, in my eyes, may be thus summed up; that it is susceptible of being indefinitely perfected in proportion as experience and observation become more accurate and reasoning more rigorous. The modern system, on the contrary, which has said its last word in the integration of a differential equation modified in order to render the integration possible, cannot make a single step in advance so long as the science of integration is itself stationary.

MR. R. E. FROUDE'S REPLY TO M. BERTIN'S REMARKS.

I will take M. Bertin's remarks in his own order.

(*a*) Water Chamber Extinction.—For the benefit of those to whom it may not be convenient to refer to Mr. Watts' 1885 paper,* I will remark that the results referred to by M. Bertin were obtained with a model of the water chamber of the *Edinburgh*, mounted on a pendulum; one side of the model

* Trans. I.N.A., Vol. XXIV. p. 30.

chamber being of glass, so that the actual movement of the water was readily observed. Under certain conditions of experiment, up to certain amplitudes, the reciprocating displacement of the C. G. of the water was visibly such as I understand to be contemplated by M. Bertin; such, namely, as to modify the effective stability, and thereby the period, but not to cause resistance to the rolling. In this kind of movement the C. G. crossed the middle line at the mid-swing of the pendulum. But under these conditions of experiment the presence of the water was found to cause no extinction; whereas, under the conditions referred to by M. Bertin, the movement of the water was quite different. In this latter kind of movement, the C. G. crossed the middle line at about the end of the swing, and in the direction of the downward slope, so that the C. G. was always on the ascending side. This kind of movement of the weight of the water must necessarily operate, as was pointed out in Mr. Watts' paper, to check or extinguish the rolling, just as, and for the same reason as, the movement of the weight of the men running tends to increase the rolling. Not only so, but the observed degree of this movement of the water was, in fact, just such as should suffice to thus cause the observed extinction.

The explanation, then, of the extinction of the rolling, if that is all that is required, lies simply in the observed fact of this movement of the contained water. If it be asked, further, what becomes of the work taken up by the water in thus extinguishing the rolling, the answer is, that this work is absorbed in the violent frothing and whirling which was seen to accompany, or rather follow, the descent of the water from one end of the chamber to the other; just as work is absorbed when a wave breaks on a beach, or when water is rapidly poured out of one vessel into another.

(*b*) Viscosity Extinction.—From the circumstance that the extinction caused by the water in the water-chamber proved to be independent of amplitude of roll beyond a certain small amplitude, M. Bertin infers that the extinction of a ship without water-chamber may contain a term similarly independent of amplitude, due to the viscous resistance offered by the external water to its deformation by the movement of the hull. He infers, also, that such resistance may be unexpectedly large, from the magnitude of the water-chamber extinction relatively to the amount of water contained. But the water-chamber extinction is due to the above-described peculiar action of the C.G. of the contained water, and its constancy (as is fully explained in Mr. Watts' paper) to the limits imposed on this action by the dimensions of the chamber, these limits being reached at a small amplitude: and neither this action, nor its limitation, has any counterpart in such kind of disturbance as can take place in the external water. In any case, viscosity resistance cannot account for an extinction independent of amplitude. For viscosity resistance is a function of the speed of disturbance, as is witnessed, in the case of palpably viscous compounds such as tar or treacle, by the fact that the inclinations of surface which they may be made to temporarily assume, gradually disappear if they are left undisturbed, the surface becoming eventually as truly and uniformly level as that of still water.

(*c*) Wave-making Extinction.—To prevent misunderstanding as to the precise point in dispute, I will first broadly restate the theory of extinction of rolling by wave-making resistance; and will do so in the form of five successive propositions.

(1) A floating spar, or other long floating solid of revolution, if given a regularly reciprocating bodily sideways motion, will generate a train of waves travelling away from it in each direction, at the speed proper to the period of reciprocation; gradually covering more and more of the surface with waves so long as the motion is continued.

(2) Such reciprocating bodily sideways motion, which thus generates waves, must accompany any rolling oscillation of such solid, if its C. G. is below its axis, as it must be for the body to float stably.

(3) Other floating bodies, even though not true solids of revolution, such as the hulls of ships, will have a general tendency to cause waves, when rolling in the same way.

(4) The work involved in the continual causation of waves must in such cases come out of the rolling, and so involve extinction; and the mathematics show that such extinction must be proportional to the simple power of the amplitude.

(5) The analysis of curves of extinction of ships may be, therefore, expected to exhibit a term of extinction proportional to amplitude, due to wave-making.

Now, I understand that M. Bertin does not dispute the above propositions (1) to (4); but he contends, at the same time, that the extinction arising from submerged disturbance of the external water must, owing to the wave-making, be less than would so arise if wave-making were prevented (as, *e.g.*, if the surface were closed over), by an amount greater than the extinction actually due to the wave-making.

To this I reply, in the first place, that, even were this contention valid, it would not invalidate proposition (5). For, in the case of any given ship at varying amplitude, the extinction due to wave-making would still appear as a positive term, proportional to the amplitude, in addition to whatever extinction remained, due to submerged resistance; this being itself also necessarily a positive term, increasing according to some function or other of the amplitude. On M. Bertin's contention, wave-making extinction would present itself as a negative term, only in an imaginary comparison* between rolling with surface open and with surface closed.

As to the contention itself, as a point of principle—irrelevant indeed, as I have just hinted, to the precise question which I understand to be here at issue—if it amounted simply to this, that freeing of surface may in some cases reduce total resistance, by subtracting from submerged resistance more than wave-making adds, I would freely admit it. An imperfectly immersed oar blade, for example, suggests itself at once as a case in point. But if the contention is, as M. Bertin's argument seems to require, not that this may happen in some cases, but that it must happen in all cases, then I cannot for a moment admit it. Such a contention is too sweeping, and the subject too intricate, to be adequately argued here. It must suffice to urge that such contention is radically inconsistent with what has been accepted unchallenged for from twenty to thirty years past as the true theory of resistance of ships; and that, as a preliminary to entertaining it, even as a subject for argument, we may fairly call upon M. Bertin to advance a stronger *prima facie* case in its favour than is afforded by the dictum that the water "assumes the movement which allows it to make way with the least possible resisting work." Does the water do this, for example, when it forms waves under the action of the wind gliding over its originally unruffled surface?

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* M. Bertin appears to argue that this comparison is not in effect wholly imaginary, in that the condition of rolling under headway may be taken as sensibly equivalent to that of rolling with closed surface. But, considering that the laterally dispersive speed of the waves created by the rolling must generally be some two or three times the full speed of the ship, it seems impossible, on any grounds, to suppose that headway can markedly modify the wave-making due to rolling.

(*d*) Modes of Investigation.—I am glad to have elicited from M. Bertin the interesting statements concerning the early history of the investigations of Rolling, with which his remarks conclude. It is most interesting to learn, concerning the integration of the differential equation of rolling, what we knew already concerning the formulation of the law of comparison between ships and models, namely, that the late Mr. W. Froude, without knowing it, had been in fact anticipated by M. Reech, and it would seem that, in both instances alike, Reech's solution remained an academic formula, little known beyond the school of that illustrious Professor, until independently determined and developed in practical import by Mr. W. Froude.

For the rest, I ask permission, on my side, to disclaim for my paper any intention either of classifying different modes of investigation of rolling according to date, of favouring exclusive recourse to the mathematical integration, or of deprecating the study of the curves of extinction, and the procedure by reckoning the increment of rolling which successive waves tend to cause, against the decrement of rolling due to extinction. Indeed, the chief aim of my own paper is to show in effect how the propositions commonly derived from the mathematical integration may subserve this latter procedure; and, indeed, such procedure, unless it is to be quite blindly empirical, must be provisionally based on at least a tacit appeal to some kind of simplifying assumptions and some kind of integration of the wave effect. M. Bertin's method is itself in this sense so based, and my objection to it is, not that the nature of the method is bad, but rather that, in the choice of such provisional basis, he has disused the materials supplied by the existing science, not of rolling merely, but of harmonics in general, and fallen back upon purely tentative hypotheses, such as befit the first examination of an entirely novel kind of problem. This, and not that the method was in fact old, was my meaning in describing M. Bertin's method as retrograde.

A NEW THEORY OF THE PITCHING MOTION OF SHIPS ON WAVES, AND OF THE STRESSES PRODUCED BY THIS MOTION.*

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[Read at the Thirty-seventh Session of the Institution of Naval Architects, March 27, 1896; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

Thirty-five years ago the late Mr. W. Froude gave his theory of the rolling of ships, which is now classical. This theory was the point of departure of the series of investigations on the same subject connected with such famous names as those of J. Scott-Russell, Professor Rankine, M. E. Bertin, M. B. de Saint-Venant, Mr. Froude, jun., and others.

These investigations are so well known that they need not be repeated here; it is sufficient to say that their result is that, the rolling of a ship on given waves can be calculated to a sufficient approximation for practical purposes, especially if by previous experiments with the ship herself, or with her model, the co-efficients of extinction have been determined.

The state of the question of the pitching motion of a ship is quite another one. There exists no theory of this motion; no experiments have been made since those of M. Bertin with his "oscillographe double"; there is no method of treating the question mathematically, that of the late Mr. W. Froude being inapplicable, because his fundamental hypotheses were that, the transverse dimensions of a ship are small in comparison with those of the profiles of waves, and that the centre of gravity of the ship moves, in a given manner, on the same circular orbit as the particles of water. These hypotheses are not satisfied in the case of pitching. The length of the ship may even be greater than that of the wave, and the motion of her centre of gravity may be quite a different one.

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* An abstract of the mathematical part of this paper was communicated by me to M. Guyou, who did me the honour of presenting it to the Paris Academy of Sciences, and of inserting it in the "Comptes Rendus" ("C. R.," No. 4, 1896).

Notwithstanding this, the question of the pitching of ships presents, for a shipbuilder at least, the same amount of interest as the rolling for a seaman, because the stresses, to which the different parts of the hull of a ship are subjected, can be calculated, to a sufficient degree of approximation, only when the pitching is known.

In this paper I present an entirely new theory of pitching, independently of the late Mr. W. Froude's hypotheses. The paper is divided into three parts: the first contains the exposition of the results of the theory and a general sketch of it and of its practical applications set forth in the simplest possible manner; the second, entitled "Appendix," is devoted to the full mathematical development of the theory, and to the proofs of the rules stated and used in the first part; and the third contains all the numerical examples and calculations to illustrate the theory and its applications. The method used in the Appendix for the mathematical treatment of the pitching is that of successive approximations and development in series, in the same manner as used in physical astronomy for calculating the perturbed motion of planets.

I.

§ 1. The mathematical theory of the pitching of ships now proposed is fully explained and developed in the Appendix to this paper. It appears therefrom that the pitching of a ship and her vertical oscillations can be calculated by it with sufficient accuracy in a very simple manner.

Plates LIV., LV., and LVI. give an example of the results of such a calculation.

The first of these plates represents the motion of a ship having a displacement of nearly 5,000 tons, length, 350 ft., breadth, 48 ft. 6 in., and draught of water 19 ft., on waves 420 ft. long, 16 ft. 6 in. high, with a period of 9 seconds, the ship being supposed not to have any forward motion, her bow being turned in the direction of the motion of the waves.

Plate LIV. represents eight successive positions of the ship during the 9 seconds which it takes for a single wave to run along the ship's sides.

All the positions are drawn according to the calculated results, the formula being given on the plate itself. If the ship has a forward motion and a proper velocity of her own, then her pitching takes another form.

To show this more clearly, Plates LV. and LVI. have been constructed. Plate LV. represents the same ship on the same waves, but steaming 12·5 knots in the direction of the motion of the waves. The velocity of the waves being nearly 32 knots, they run along the ship's sides with a relative velocity of nearly 20 knots from stern to bow. The apparent period of the waves in this case is no longer 9 seconds but 16 seconds, and such

is the period of the pitching, whose amplitude is at the same time reduced, and the behaviour of the ship (as to pitching) becomes better than in the previous case.

Plate LVI. represents the same ship on the same waves, but steaming with the same velocity, 12·5 knots, against the waves. We see immediately that the behaviour of the ship is very much worse. The pitching, instead of being 4° as in the second case, is increased up to 8°; but it is not merely the absolute value of the pitching that is so important, as the *value* of the phase of the ship's position with relation to that of the wave.

In the first two cases, and especially in the second one, we see that when the crest of the wave has reached the bow of the ship she has taken her highest position with the bow upward, when the bottom of the wave is by the bow the position of the ship is at its lowest. In a word, there is a complete coincidence in the motion of the ship and the motion of the wave, the ship rises slightly on the waves, she is "seaworthy;" mathematically there is no difference in the phase of the wave and ship.

But in the third case, we see that there is a retardation in the ship against the wave, therefore the ship plunges in the wave, she is not seaworthy; and, taking into account the amplitude of the pitching and the emersion of the screws, we see that it is practically impossible for this ship to steam at the supposed velocity against such waves.

The velocity of the ship must be reduced till the amplitude of the pitching and the emersion of the screws is no longer excessive. This velocity will be found by trial on repeating the calculation of the apparent period of the wave and the corresponding motion of the ship.

§ 2. There is another question which arises, and which can also be solved by calculation. This is, what are the dimensions of the ship which could steam with a given velocity against given waves with the condition that the amplitude of pitching remains a tolerable one?

The solution of this question can be obtained in the following manner:—We draw a ship, having the forms we need to satisfy other conditions of her design, but her size is left undetermined; we then take different waves whose length is variable, and we determine (by calculating the pitching produced by each of them) what must be the ratio of the length of the wave to that of the ship which will produce a tolerable pitching. Then, the length of the wave being known, and the said ratio determined, we obtain the required length of the ship.

§ 3. In the same manner an answer can be found to all questions, the solution of which depends on the true value of the pitching. One of the most important is that

of the *stress* that different parts of the ship have to withstand. The first attempt to solve this question was made by Euler, who in the year 1758 gained the prize of the French Academy by his paper, "Examen des Efforts qu'ont à supporter toutes les Pièces d'un Vaisseau dans le Roulis et le Tangage." But it was only after a hundred years that the ideas of Euler were introduced into shipbuilding practice through Sir E. Reed's celebrated paper.

Sir E. Reed's method of calculation is very well known, and has been so often discussed in the Institution of Naval Architects that I need not say much about it. I shall only call attention to the fact that, in it the ship is supposed to be in a state of equilibrium on the crest or the bottom of the wave, her immersed volume being equal to her natural displacement. The following questions immediately arise in this connection :—

(1) Is the approximation so obtained sufficient; in other words, is it possible to neglect the *inertia* of the ship's pitching motion ?

(2) When the ship pitches and makes vertical oscillations her displacement is a variable one ; the ship, in rising on a wave (when the crest comes to the middle) obtains a vertical velocity—a translational one, the *vis viva* of which must be compensated by the work of the vertical forces acting on the ship. But these forces, so long as the buoyancy of the ship remains constant, are balanced, thus the ship must *rise* from the water to such a height that the work done by the *unbalanced* weight compensates the said *vis viva*. Thus the buoyancy, when the ship is on the crest of the wave, will be *less* than the ship's weight, and the bending moments *greater* than those calculated on Sir E. Reed's assumptions.

(3) As there is pitching there are external moments of forces which produce it. These moments must be added to those which are calculated on the hypothesis of equilibrium, taking, of course, the ship's inertia into account.

The pitching of the ship and her vertical oscillations being determined, the required bending moments can immediately be calculated. To obtain them it is only necessary to calculate the bending moment on still water, and to add those which arise from the inertia of the ship and from the action of the wave. This calculation could be made from the plates showing the positions of the ship, but as these positions are only a representation of analytical formulæ, we can use the formulæ themselves, and so obtain an analytical expression of the bending moment as a function of the time, and then find its maximum positive and negative values. It is shown in the numerical example how to make such calculations ; to make their result clearer we have drawn Fig. 1, Plate LVII., which corresponds to Plate LIV. In this last are shown eight successive positions of the ship on the wave ; on Plate LVII. are indicated, by the

ordinates drawn, the corresponding bending moments at the middle section of the ship. The curve itself shows the variation of the moment as a function of the time, or—what is the same thing—of the distance of the bottom of the wave from the middle.

These plates and the calculation mentioned above show that, if on still water the positive bending moment (both bow and stern having a tendency to be lowered) is $\frac{1}{60}$ P L—that is, $\frac{1}{60}$ of the product of the weight of the ship by her length—the bending moment does not attain its maximum positive value when the ship is on the crest of the wave, nor its maximum negative value when the ship is on the bottom. By the action of the forces of inertia and of the wave these values correspond to those positions of the ship when her bow reaches the highest or the lowest position, whilst the angle of pitching reaches its maximum value.

In our example the greatest positive moment is $\frac{1}{49}$ P L.

In this example the length of the wave is about $1\frac{1}{5}$ of that of the ship, and it would be too long a matter to examine to what a ratio of these two lengths, and to what a direction of the ship's head relatively to the crest of waves, corresponds the greatest bending moment ; we shall do it in a special paper.

§ 4. We have only considered the case of the pure pitching of a ship steaming at right angles to the crest of the waves. This is, of course, but an ideal case, as pitching is almost always accompanied by rolling. This general case can also be treated mathematically, and we shall do this in another paper, the method being analogous to that which we now proceed to sketch.

§ 5. The pitching on waves is always accompanied by the translational oscillatory motion of the whole ship, or, what is the same, of her centre of gravity. As the horizontal oscillations do not present the same practical interest as the vertical ones, we shall only consider the latter. The principal cause of the pitching and of the said vertical oscillations is the variation of the magnitude and of the form of the immersed volume of the ship when a wave runs along her sides. If we could compute at every instant the value of the immersed volume (the effective buoyancy of the ship), and ascertain the instantaneous positions of the centre of buoyancy, we should be able to obtain immediately the equations of the pitching motion of the ship, and the whole problem would be reduced to a simple mathematical process.

To give a general sketch of the theory, and of the method, by means of which I propose to treat this question, let us consider the ideal simple case presented by the simplest of all travelling waves, viz., the sinusoidal one, represented by the equation—

$$z = r \cos 2\pi \left(\frac{x}{\lambda} - \frac{t}{\tau}\right) \qquad (1)$$

r is half of the height of a wave, λ its length, τ its period. On giving successive

values to the time t, we see that the wave runs in the direction of the positive x axis with a uniform velocity $\frac{\lambda}{\tau}$.

Let a ship (Fig. 2, Plate LVII.) whose centre of gravity is G be at rest, her bow turned in the direction of the running of the waves. If only vertical oscillations and pitching are considered, the position of the ship is fully determined by the ordinate ζ of her centre of gravity reckoned from the zero plane 00, and by the angle θ of her inclination about the transverse axis passing through the centre of gravity.

If $F F_1$ is the natural load water line of the ship and the point E is the centre of gravity of its area, we see at once that at the moment t the immersed volume of the ship differs from her displacement V_0, corresponding to the natural L.W.L., by the shaded volume v contained between the load water line and the instantaneous position of the wave. The angle of inclination θ being not greater than 6° to 10°, its cosine is practically equal to 1, and its sine and tangent to the absolute measure of the angle itself. Evidently the distance N H of the point N of the L.W.L., whose abscissa, $G N = x$, from the zero plane is $N H = \zeta + \theta x$; the corresponding ordinate of the surface of water being $z_1 = H K$, we see that the volume v can be expressed by the following integral:—

$$v = \int_{-L_1}^{+L_2} (H N - H K) y \, . \, d x = \int_{-L_1}^{+L_2} (\zeta + \theta x - z_1) y \, . \, d x; \qquad (2)$$

where y is the ordinate of the L.W.L., corresponding to the abscissa value x and $L_1 = G F$, and $L_2 = G F_1$.

Then we have—

$$v = \zeta \int_{-L_1}^{+L_2} y \, d x + \theta \int_{-L_1}^{+L_2} x y \, d x - \int_{-L_1}^{+L_2} z_1 y \, d x. \qquad (3)$$

But, as—

$$\int_{-L_1}^{+L_2} y \, d x = S_0 = \text{the area of the L.W.L.}, \qquad (4)$$

$$\int_{-L_1}^{+L_2} x y \, d x = l \, . \, S_0 = \text{moment of the area } S_0 \text{ about the point G}, \qquad (5)$$

it remains only to calculate the third of these integrals, viz.—

$$\int_{-L_1}^{+L_2} z_1 y \, d x,$$

which expresses the variable part of the volume v depending on the position of the wave relatively to the ship. Putting for z_1 its value (1) we obtain—

$$\int_{-L_1}^{+L_2} z_1 y \, d x = r \int_{-L_1}^{+L_2} y \, . \cos 2\pi \left(\frac{x}{\lambda} - \frac{t}{\tau}\right) d x$$

$$= r \cos \frac{2\pi t}{\tau} \cdot \int_{-L_1}^{+L_2} y \cos \frac{2\pi x}{\lambda} d x + r \sin \frac{2\pi t}{\tau} \int_{-L_1}^{+L_2} y \sin \frac{2\pi x}{\lambda} d x$$

$$= r a'_0 \cos \frac{2\pi t}{\tau} + r b'_0 \sin \frac{2\pi t}{\tau} \tag{6}$$

where—

$$a'_0 = \int_{-L_1}^{+L_2} y \cos \frac{2\pi x}{\lambda} d x ; \quad b'_0 = \int_{-L_1}^{+L_2} y \sin \frac{2\pi x}{\lambda} d x. \tag{7}$$

a'_0 and b'_0 are two constants for a given ship and a given *length* of wave, they are immediately calculable by one of the approximate formulæ, as Simpson's or any other, the y being taken from the drawings of the ship. Quite in the same manner taking the moment of v about the transverse axis, we obtain—

$$M = \int_{-L_1}^{+L_2} x (\zeta + \theta x - z_1) \, y \, d x = \zeta \int_{-L_1}^{+L_2} x y \, d x + \theta \int_{-L_1}^{+L_2} x^2 y \, d x - \int_{-L_1}^{+L_2} z_1 x y \, d x$$

$$= \zeta S_0 l + \theta I - \int_{-L_1}^{+L_2} z_1 x y \, d x ; \tag{8}$$

here—

$$I = \int_{-L_1}^{+L_2} x^2 y \, d x$$

is the moment of inertia of the area of the L.W.L. about the transverse axis; the part of the moment M proceeding from the wave, viz. :—

$$\int_{-L_1}^{+L_2} z_1 x y \, d x,$$

by the same transformation as above, takes the form :—

$$\int_{-L_1}^{+L_2} z_1 x y \, d x = r a'_1 \cos \frac{2\pi t}{\tau} + r b'_1 \sin \frac{2\pi t}{\tau} \tag{9}$$

where—

$$a'_1 = \int_{-L_1}^{+L_2} y x \cos \frac{2\pi x}{\lambda} d x ; \qquad b'_1 = \int_{-L_1}^{+L_2} y x \sin \frac{2\pi x}{\lambda} d x \tag{10}$$

a'_1 and b'_1 being also two constants for a given ship, and a given length of wave λ.

In most of the modern ships the centre of gravity G is so near to the middle of the length that, practically, $L_1 = L_2$, and also $l = 0$, in which cases expressions for the volume v and the moment M become simpler.

If buoyancy on waves could be calculated in the same manner as on still water (had the pressure in the wave been a hydrostatical one), we would then obtain the force acting on the ship and its moment, by multiplying v and M by the weight q of a cubic foot of water, and adding to M the moment $P . a . \theta$ of the ship's buoyancy, where a is the distance between the centre of gravity G and the centre of buoyancy C.

Then, to obtain the required equations, it remains only to compute the resistance of water to the ship's oscillations. It is convenient for the sake of simplicity to assume the resistance as proportional to the first power of the velocity, by properly choosing the co-efficient. Indeed, whatever the law of resistance may be on representing it by a curve, we need only the part of this curve between O and the maximum velocity u, which seldom reaches 3 ft. per second, the chord O B (Fig. 3, Plate LVII.) can be approximately substituted for this part of the curve, the tangent of the angle of inclination of this chord is the required co-efficient of resistance.

We show by a numerical example that, even large errors in the value of the resistance, have but little influence on the final result, so that a rough approximation for the resistance is quite sufficient. Designating by 2 N and $2 N_1$ the co-efficients of resistance to the vertical oscillations and to the pitching, we obtain for our case of a sinusoidal wave the following two equations of motion :—

$$\frac{P}{g}\frac{d^2\zeta}{dt^2} + 2 N \frac{d\zeta}{dt} + q S_0 \zeta = q r a'_0 \cos\frac{2\pi t}{\tau} + q r b'_0 \sin\frac{2\pi t}{\tau} \qquad (11)$$

$$K\frac{d^2\theta}{dt^2} + 2 N_1 \frac{d\theta}{dt} + P (R - a)\theta = q r a'_1 \cos\frac{2\pi t}{\tau} + q r b'_1 \sin\frac{2\pi t}{\tau} \qquad (12)$$

where K is the moment of inertia of the ship about the transverse axis, $R = \frac{I}{V_0}$ is the elevation of the longitudinal metacentre above the centre of buoyancy, a'_0, b'_0, a'_1, b'_1 having the values given by the formulæ (7) and (10).

These two equations being linear ones and with constant co-efficients, their integration and discussion do not present any difficulties.

§ 6. But the pressure in the wave is not a hydrostatical one, so that the buoyancy on the wave is not equal to the product of the immersed volume by the weight q of a cubic foot of water ; further, the wave is not generally a sinusoidal one, but a trochoidal one, as shown by Rankine. A special mathematical investigation is therefore necessary. It is fully made in the Appendix to this paper, the above pages being only intended to give a general sketch of this theory, to show its difference

from any other hitherto proposed, and in view of the short time given in the Institution for reading a paper of such a mathematical and naturally somewhat complex character.

This detailed theory shows that the corrections to be made in the equations (11) and (12) are of very little importance, so that these equations are quite sufficient for most practical purposes.

The manner of performing the calculations is fully illustrated by the numerical examples.

§ 7. We have only considered the ideal case of pure pitching, the ship steaming at right angles to the crests of the waves. If this angle is an oblique one, then pitching is accompanied by rolling, the problem becomes of a still more complex character, but the method of solution given in the Appendix is also applicable to it, as we shall show in another paper.

APPENDIX I.

§ 1. The late Professor Rankine in the year 1863 gave a theory of waves extraordinary in its elegance. It was the only exact solution known of the hydrodynamical equations until the year 1894, when M. Guyou found a second one which corresponds to the heaving of the sea (Clapotis).

I shall suppose the waves trochoidal, which is a more general case.

All the properties of such waves are expressed by the following three equations:—

$$x - a = r\, e^{-\frac{2\pi c}{\lambda}} \sin 2\pi \left(\frac{a}{\lambda} - \frac{t}{\tau}\right) \tag{1}$$

$$z - c = r\, e^{-\frac{2\pi c}{\lambda}} \cos 2\pi \left(\frac{a}{\lambda} - \frac{t}{\tau}\right) \tag{2}$$

$$p - p_0 = g\rho \left[c - \frac{\pi}{\lambda} r^2 \left(1 - e^{-\frac{4\pi c}{\lambda}}\right) \right] \tag{3}$$

where the notation has the following meaning: a and c are the co-ordinates of the centre of oscillation of that particle of which they were the co-ordinates in still water, r is the radius of the orbit described by the particles of the free surface of water (half height of the wave), λ is the length of the wave, τ its period, x and z the co-ordinates of the particle (a, c) at the moment t, ρ the density of water, g the force of gravity, p_0 the atmospheric pressure, p the pressure in that layer of fluid whose initial immersion was c.

§ 2. Let us suppose a ship steaming with the waves in the direction of their motion, then her longitudinal plan will coincide with the plan of the $z\,x$. For the sake of simplifying the following

calculations, let us suppose also that the centre of gravity of the ship coincides with that of the area of her load water line (if there was a considerable distance between these two points it would be very easy to make the corresponding correction, which, however, in most cases can be neglected).

The horizontal motion of the centre of gravity of the ship does not present the same interest as its vertical oscillations, so that we shall only consider these last, and therefore we may draw the axis of z vertically downwards through the ship's centre of gravity. The axis of the positive x being directed towards the bow. This being admitted, the position of the ship is fully determined by the ordinate ζ of her centre of gravity, and by the angle θ of her inclination about the transverse axis. We shall reckon this angle positively when the bow of the ship is lowered.

The forces acting on the ship are the following:—

(1) Her weight $P = g \rho V_0$, where V_0 is the displacement of the ship in still water;

(2) The hydrodynamical pressure p acting on all the elements of the immersed surface of the ship; and

(3) The resistance R of water to the ship's oscillations.

It is necessary not to conceal but to make use of the hypothesis which must be made upon the action of the hydrodynamical pressure, that is, that, in spite of the presence of the ship, the pressure in the wave has the value determined by the equation (3) of the wave motion. This hypothesis is one of the late Mr. W. Froude's, and the single one which is necessary for our theory. The results of Froude's theory of rolling, being confirmed by experience, show that this hypothesis is sufficiently near to the truth, at least for practical purposes.

Taking the projections of all the forces on the axis of z, and their moments about the transverse axis, we form the following two equations of the vertical oscillations of the ship, and of her pitching motion:—

$$\frac{P}{g}\frac{d^2\zeta}{d\,t^2} = P - \int_s p \cos(\widehat{n\,z})\, d\,s - R \qquad (4)$$

$$K\frac{d^2\theta}{d\,t^2} = -\int_s \left[x p \cos(\widehat{n\,z}) - z\, p \cos(\widehat{n\,x}) \right] d\,s - M_R \qquad (5)$$

where all the integrals are taken for the whole immersed surface of the ship at the moment t, $(\widehat{n\,x})$ and $(\widehat{n\,z})$ being the angles formed by the external normal with the axes of x and z, R is the projection of the resistance of water on the axis of z, and M_R the moment of the resistance about the transverse axis, K the moment of inertia about the same axis, which being at right angles to the longitudinal plane of the ship is a principal one.

§ 3. In such a form, in spite of its apparent simplicity, these equations present the utmost difficulties for practical calculation. Accordingly, it is necessary to transform them in such a manner that all the data could be immediately taken from the drawings of the ship.

This transformation can be effected as follows: at first, the surface integrals must be transformed by the very well-known formula for such integrals as correspond to the whole immersed volume V.

Thus, we have:

$$\int_s p \cos(\widehat{n\,z})\, d\,s - \int_v \frac{\delta\, p}{\delta\, z} \,.\, d\,\mathrm{V} \tag{6}$$

$$\int_s \left[x\,p \cos(\widehat{n\,z}) - z\,p \cos(\widehat{n\,x}) \right] d\,s = \int_v \left(x \frac{\delta\, p}{\delta\, z} - z \frac{\delta\, p}{\delta\, x} \right) d\,\mathrm{V} \tag{7}$$

From the equations (1), (2), and (3) we obtain—

$$\frac{\delta\, p}{\delta\, x} = g\,\rho \,.\, \frac{2\,\pi}{\lambda}(x - a) \tag{8}$$

$$\frac{\delta\, p}{\delta\, z} = g\,\rho \,.\, \left[1 + \frac{2\,\pi}{\lambda}(z - c) \right] \tag{9}$$

On substituting these values in the above integrals, we see that the subintegral functions contain not only the variables x and z, but also the variables a and c; these last must be eliminated by means of the equations (1) and (2).

§ 4. This elimination is the second step of our transformation. To eliminate the variables a and c, we must solve the equations (1) and (2), but these equations being transcendental do not admit of an exact solution in finite terms. They must be solved approximatively, and therefore we must use the series, taking in them as many terms as is necessary to obtain the exactitude required for practical purposes. In order to obtain such series, we must take the well-known formula of Lagrange, by which, if u and v are two unknown functions of the variables x and z given by the equations—

$$\left.\begin{aligned} u &= x - \alpha\, \phi\,(u, v) \\ v &= z - \alpha\, \psi\,(u, v) \end{aligned}\right\} \tag{10}$$

where α is a known quantity, and $\phi\,(u, v)$ and $\psi\,(u, v)$ are given functions of the variables u, v; then any other given function $\mathrm{F}\,(u, v)$ of the same variables is represented by the following series :—

$$\mathrm{F}\,(u, v) = \mathrm{F} - \alpha \left[\phi\, \mathrm{F}'_x + \psi\, \mathrm{F}'_z \right] + \frac{\alpha^2}{1 \cdot 2} \left[\phi^2\, \mathrm{F}'_x + \psi^2\, \mathrm{F}'_z + 2\,\phi\,\psi'_x\, \mathrm{F}'_z + 2\,\phi'_z\, \psi\, \mathrm{F}'_x + \phi\,\psi\, \mathrm{F}''_{xz} \right] - \ldots \tag{11}$$

where $\mathrm{F} = \mathrm{F}\,(x, z)$; $\phi = \phi\,(x, z)$; $\psi = \psi\,(x, z)$.

In order to apply this formula to our case, we write the equations (1) and (2) in the form

$$\left(\frac{2\,\pi\, a}{\lambda} - \frac{2\,\pi\, t}{\tau} \right) = \frac{2\,\pi\, x}{\lambda} - \frac{2\,\pi\, t}{\tau} - \frac{2\,\pi\, r}{\lambda}\, e^{-\frac{2\,\pi\, c}{\lambda}} \sin 2\,\pi \left(\frac{a}{\lambda} - \frac{t}{\tau} \right) \tag{1'}$$

$$\frac{2\,\pi\, c}{\lambda} = \frac{2\,\pi\, z}{\lambda} - \frac{2\,\pi\, r}{\lambda}\, e^{-\frac{2\,\pi\, c}{\lambda}} \cos 2\,\pi \left(\frac{a}{\lambda} - \frac{t}{\tau} \right) \tag{2'}$$

then allowing—

$$u = \frac{2\,\pi\, a}{\lambda} - \frac{2\,\pi\, t}{\tau}; \qquad v = \frac{2\,\pi\, c}{\lambda}; \qquad \alpha = \frac{2\,\pi\, r}{\lambda}; \qquad x_1 = \frac{2\,\pi\, x}{\lambda} - \frac{2\,\pi\, t}{\tau}; \qquad z_1 = \frac{2\,\pi\, z}{\lambda};$$

we obtain—

$$u = x_1 - a\, e^{-v} \sin u, \qquad (1'')$$

$$v = z_1 - a\, e^{-v} \cos u, \qquad (2'')$$

two equations to which the Lagrangian formula is immediately applicable. Taking first F $(u, v) = e^{-v} \sin u$, and secondly F $(u, v) = e^{-v} \cos u$, multiplying the series obtained by $\frac{2\pi r}{\lambda}$, and restoring for x_1 and z_1, their values, we obtain the required developments—

$$\frac{2\pi}{\lambda}(x - a) = \frac{\pi r}{\lambda} e^{-\frac{2\pi z}{\lambda}} \sin 2\pi\left(\frac{x}{\lambda} - \frac{t}{\tau}\right) + \ldots . \qquad (12)$$

$$\frac{2\pi}{\lambda}(z - c) = \frac{2\pi r}{\lambda} e^{-\frac{2\pi z}{\lambda}} \cos 2\pi\left(\frac{x}{\lambda} - \frac{t}{\tau}\right) + \frac{4\pi^2 r^2}{\lambda^2} e^{-\frac{4\pi z}{\lambda}} + \ldots . \qquad (13)$$

As the terms not written down contain the third and higher powers of the small factor $\frac{2\pi r}{\lambda}$, they can all be neglected, which will be shown further.

To obtain the equation of the free surface of water at the moment t, we must make $c=0$ in the equation (1), and develop by Lagrange's formula the function $z = r \cos 2\pi\left(\frac{a}{\lambda} - \frac{t}{\tau}\right)$, having done which we obtain—

$$z_1 = \frac{\pi r^2}{\lambda} + r \cos 2\pi\left(\frac{x}{\lambda} - \frac{t}{\tau}\right) - \frac{\pi r^2}{\lambda} \cos 4\pi\left(\frac{x}{\lambda} - \frac{t}{\tau}\right) + \ldots . \qquad (14)$$

If we compare the profile traced, according to this equation, with the true trochoidal one, we shall see that for the largest waves the curves will be practically coincident; so, if we suppose the length of wave $\lambda = 500$ ft. and the height $2r = 25$ ft., and if we calculate the corresponding ordinates of the trochoid and the curve (14), we shall see that, the maximum difference between them is equal to 5 in. For the height of wave of 25 ft. it is a practically negligible quantity.

This shows that, in all our further calculations we can neglect all the quantities containing the factor $\left(\frac{2\pi r}{\lambda}\right)^3$ and content ourselves with terms containing only the first and second power of this small quantity, whose value is generally $\frac{1}{7}$, and in the most cases the second power can also be neglected.

§ 5. Having obtained these developments, we must proceed to the third step in our transformations.

On substituting the values (12) and (13) into the equations (6) and (7), we observe that the element of volume $d\,V = y\ dx\ dz$, where y is the ordinate of the ship's surface, and that the integration for x is to be performed for the whole length 2 L of the ship, and for z from the surface of water to the keel plate. If, for the sake of simplicity, we assume the ship's centre of gravity to be in the middle section, the limits of integration for x will be + L and − L; the limits for z are from z_1, the ordinate

of the disturbed surface of water, to $z_2 = h + \zeta + \theta x$, the ordinate of the keel plate h being the ship's draught of water. Thus we have—

$$\int_v \frac{\delta p}{\delta z} d\,\mathrm{V} = g\rho \int_v d\,\mathrm{V} + g\rho \int_v \frac{2\pi}{\lambda}(z - c)\, d\,\mathrm{V}$$

$$= g\rho \int_{-\mathrm{L}}^{+\mathrm{L}} d\,x \int_{z_1}^{h+\zeta+\theta x} y\, d\,z + g\rho\, a \int_{-\mathrm{L}}^{+\mathrm{L}} d\,x \int_{z_1}^{h+\zeta+\theta x} e^{-\kappa z} \cos\phi \,.\, y \,.\, d\,z + g\rho\, a^2 \int_{-\mathrm{L}}^{+\mathrm{L}} d\,x \int_{z_1}^{h+\zeta+\theta x} e^{-2\kappa z}\, y\, d\,z \qquad (15)$$

where for brevity's sake $a = \frac{2\pi r}{\lambda}$; $\kappa = \frac{2\pi}{\lambda}$, and $\phi = 2\pi\left(\frac{x}{\lambda} - \frac{t}{\tau}\right)$.

The upper limits of these integrals contain the two variables ζ and θ, for the determination of which we form our differential equations; accordingly a further transformation is necessary; we shall therefore divide all these integrals into two parts, the first one with variable limits, but with a constant instead of the sub-integral function, the other part with constant limits. We shall make the calculation in full for the two first integrals of the formula (15), for all the others it will be quite the same, and we shall give only the final result.

For t e first integral (15) we have—

$$\int_{-\mathrm{L}}^{+\mathrm{L}} d\,x \int_{z_1}^{h+\zeta+\theta x} y\, d\,z = \int_{-\mathrm{L}}^{+\mathrm{L}} d\,x \int_{z_1}^{\zeta+\theta x} y\, d\,z + \int_{-\mathrm{L}}^{+\mathrm{L}} d\,x \int_{\zeta+\theta x}^{h+\zeta+\theta x} y\, d\,z \qquad (16)$$

As the first of the last two integrals relates only to the parts of the ship close to her L.W.L., we can assume for a first approximation that these parts are cylindrical, that is, that they are at right angles to the water line (the correction for the want of perpendicularity will be made afterwards). Then y is independent of z and equal to y_0, the corresponding ordinate of the load water line, and

$$\int_{z_1}^{\zeta+\theta x} y\, d\,z = y_0(\zeta + \theta x - z_1)$$

then

$$\int_{-\mathrm{L}}^{+\mathrm{L}} d\,x \int_{z_1}^{\zeta+\theta x} y\, d\,z = \zeta \int_{-\mathrm{L}}^{+\mathrm{L}} y_0\, d\,x + \theta \int_{-\mathrm{L}}^{+\mathrm{L}} x\, y_0\, d\,x - \int_{-\mathrm{L}}^{+\mathrm{L}} z_1 y_0\, d\,x$$

Here the integrals—

$\int_{-\mathrm{L}}^{+\mathrm{L}} y_0\, d\,x = \mathrm{S}_0 =$ area of the load water line;

$\int_{-\mathrm{L}}^{+\mathrm{L}} x_1 y_0\, d\,x = \mathrm{S}_0 \,.\, l$ statical moment of the area S_0 about the transverse axis. In most cases it is negligible, that is $l = 0$.

It remains to calculate the integral $\int_{-\mathrm{L}}^{+\mathrm{L}} z_1 y_0\, d\,x$.

Taking for z_1 its value (14) we obtain—

$$\int_{-L}^{+L} z_1 y_0 \, d x = \frac{\pi r^2}{\lambda} S_0 + r \int_{-L}^{+L} y_0 \cos 2 \pi \left(\frac{x}{\lambda} - \frac{t}{\tau}\right) d x - \frac{\pi r^2}{\lambda} \int_{-L}^{+L} y_0 \cos 4 \pi \left(\frac{x}{\lambda} - \frac{t}{\tau}\right) d x$$

$$= \frac{\pi r^2}{\lambda} S_0 + r a'_0 \cos \frac{2 \pi t}{\tau} + r b'_0 \sin \frac{2 \pi t}{\tau} - \frac{\pi r^2}{\lambda} a''_0 \cos \frac{4 \pi t}{\tau}$$

$$- \frac{\pi r^2}{\lambda} b''_0 \sin \frac{4 \pi t}{\tau}, \qquad (17)$$

where—

$$a'_0 = \int_{-L}^{+L} y_0 \cos \frac{2 \pi x}{\lambda} d x \; ; \quad b'_0 = \int_{-L}^{+L} y_0 \sin \frac{2 \pi x}{\lambda} d x \; ;$$

$$a''_0 = \int_{-L}^{+L} y_0 \cos \frac{4 \pi x}{\lambda} d x \; ; \quad b''_0 = \int_{-L}^{+L} y_0 \sin \frac{4 \pi x}{\lambda} d x.$$

For a given length of wave λ, the constants : a'_0, b'_0, a''_0, b''_0, are immediately calculable by any one of the approximate formulæ, as Simpson's, or any other, y_0 being given by the drawings of the ship.

To calculate the integral $\int_{-L}^{+L} d x \int_{\zeta + \theta x}^{h + \zeta + \theta x} y \, d z$ we make $z = z' + \zeta + \theta x$, then the limits become constant and we obtain—

$$\int_{-L}^{+L} d x \int_{\zeta + \theta x}^{h + \zeta + \theta x} y \, d x = \int_{-L}^{+L} d x \int_{0}^{h} y \, d z' = V_0$$

where V_0 is the displacement of the ship in her upright natural position on still water.

For calculating the integrals containing the exponential $e^{-\kappa z}$, we proceed in the same manner as will be shown for the integral : $\int_{-L}^{+L} d x \int_{z_1}^{h + \zeta + \theta x} e^{-\kappa z} y \, . \cos \phi \, d z$.

As formerly—

$$\int_{-L}^{+L} d x \int_{z_1}^{h + \zeta + \theta x} e^{-\kappa z} y \cos \phi \, d z = \int_{-L}^{+L} d x \int_{z_1}^{\zeta + \theta x} y e^{-\kappa z} \cos \phi \, d z + \int_{-L}^{+L} d x \int_{\zeta + \theta x}^{h + \zeta + \theta} y e^{-\kappa z} \cos \phi \, d z \qquad (18)$$

$$= \int_{-L}^{+L} y_0 \cos \phi \, . \, d x \int_{z_1}^{\zeta + \theta x} e^{-\kappa} \, d z + \int_{-L}^{+L} e^{-\kappa (\zeta + \theta x)} \cos \phi \, d x \int_{0}^{h} e^{-\kappa z'} y \, d z'.$$

All these terms being finally multiplied by the small factor α, and the value of $\zeta + \theta x$, representing the amplitude of the vertical oscillations of the different points of the ship being small relatively to the length of wave λ, we can expand the exponential $e^{-\kappa (\zeta + \theta x)} = e^{-\frac{2 \pi}{\lambda} (\zeta + \theta x)}$ in series, and content ourselves with the first powers (numerical calculation given below shows the extreme smallness of the terms so neglected). In this way we obtain—

$$\int_{-L}^{+L} \cos \phi \, . \, d x \int_{z_1}^{h + \zeta + \theta x} e^{-\kappa z} y \, d z = \zeta \int_{-L}^{+L} y_0 \cos \phi \, d x + \theta \int_{-L}^{+L} y_0 x \cos \phi \, d x$$

$$- \int_{-L}^{+L} y_0 z_1 \cos\phi \, d\,x + (1 - \kappa\,\zeta) \int_{-L}^{+L} d\,x \int_0^h e^{-\kappa z'} y \cos\phi \, d\,z'$$

$$- \kappa\,\theta \int_{-L}^{+L} d\,x \int_0^h e^{-\kappa z} y \,.\, x \,.\, \cos\phi \,.\, d\,z'.$$

Putting for $\cos\phi$ its value—

$$\cos\phi = \cos 2\pi \left(\frac{x}{\lambda} - \frac{t}{\tau}\right) = \cos\frac{2\pi x}{\lambda} \cos\frac{2\pi t}{\tau} + \sin\frac{2\pi x}{\lambda} \sin\frac{2\pi t}{\tau}$$

and separating the terms multiplied by the $\cos\frac{2\pi t}{\tau}$ from those with the $\sin\frac{2\pi t}{\tau}$, we have—

$$\begin{aligned}
\int_{L}^{+L} \cos\phi \, d\,x \int_{z_1}^{h+\zeta+\theta x} e^{-\kappa z} y \, d\,z = {} & a'_0 \zeta \cos\frac{2\pi t}{\tau} + b'_0 \zeta \sin\frac{2\pi t}{\tau} \\
& + a'_1 \theta \cos\frac{2\pi t}{\tau} + b'_1 \theta \sin\frac{2\pi t}{\tau} - \frac{1}{2} r \, S_0 \\
& - \frac{1}{2} r \, a''_0 \cos\frac{4\pi t}{\tau} - \frac{1}{2} r \, b''_0 \sin\frac{4\pi t}{\tau} + \\
& + (1 - \kappa\,\zeta) \left[A'_0 \cos\frac{2\pi t}{\tau} + B'_0 \sin\frac{2\pi t}{\tau} \right] \\
& - \kappa\,\theta \left[A'_1 \cos\frac{2\pi t}{\tau} + B'_1 \sin\frac{2\pi t}{\tau} \right] . \; . \; . \; . \qquad (19)
\end{aligned}$$

where a'_0, a'_1 . . . . A'_0, A'_1, B'_0, B'_1, have the values shown by the formulæ (23) given further on, and are immediately calculable from the drawings of the ship.

§ 6. On computing in the same manner, and with the same degree of approximation, all the integrals which arise from the transformation of the resultant pressure given by formula (6), and of the resultant moment of the hydrodynamical pressure as expressed by the formula (7), and substituting the values found in the differential equations (4) and (5), we give them the following form, though complicated by its external appearance, but very convenient for the numerical calculation.

As explained in the first part of the paper, resistance of water is assumed proportional to the first power of the velocity.

The required equations are then—

$$\begin{aligned}
& \frac{P}{g} \frac{d^2 \zeta}{d\,t^2} + 2\,N \frac{d\,\zeta}{d\,t} + g\,\rho\,S_0\,\zeta = g\,\rho \Big\{ r\,m'_0 \cos\frac{2\pi t}{\tau} + r\,n'_0 \sin\frac{2\pi t}{\tau} + \alpha\,r\,H_0 \\
& - \alpha \left[\zeta\,m'_0 + \theta\,m'_1 \right] \cos\frac{2\pi t}{\tau} - \alpha \left[\zeta\,n'_0 + \theta\,n'_1 \right] \sin\frac{2\pi t}{\tau} \Big\} + \; . \; . \; . \; . \qquad (20) \\
& K \frac{d^2\theta}{d\,t^2} + 2\,N_1 \frac{d\,\theta}{d\,t} + g\,\rho\,V_0 (R - a)\,\theta = g\,\rho \Big\{ r\,e'_1 \cos\frac{2\pi t}{\tau} + r\,g'_1 \sin\frac{2\pi t}{\tau} \\
& + \alpha \left[\zeta\,h'_1 + \theta\,h'_2 \right] \cos\frac{2\pi t}{\tau} + \alpha \left[\zeta\,f'_1 + \theta\,f'_2 \right] \sin\frac{2\pi t}{\tau} - \frac{\alpha}{2} \left[n'_0\,\zeta^2 + 2\,n'_1\,\zeta\,\theta + n'_2\,\theta^2 \right] \cos\frac{2\pi t}{\tau} \\
& + \frac{\alpha}{2} \left[m'_0\,\zeta^2 + 2\,m'_1\,\zeta\,\theta + m'_2\,\theta^2 \right] \sin\frac{2\pi t}{\tau} + \; . \; . \; . \; . \Big\} \qquad (21)
\end{aligned}$$

only terms containing the first powers of the small factor $\alpha = \frac{2\pi r}{\lambda}$ being retained, all others neglected. The letters have the following meaning :—

$$\left.\begin{array}{ll}
m'_0 = a'_0 - \kappa A'_0 & n'_0 = b'_0 - \kappa B'_0 \\
m'_1 = a'_1 - \kappa A'_1 & n'_1 = b'_1 - \kappa B'_1 \\
m'_2 = a'_2 - \kappa A'_2 & n'_2 = b'_2 - \kappa B'_2 \\
e'_1 = a'_1 + \kappa D'_0 & g'_1 = b'_1 - \kappa C'_0 \\
e'_2 = a'_2 + \kappa D'_1 & g'_2 = b'_2 - \kappa C'_1 \\
h'_1 = e'_1 - B'_0 & f'_1 = g'_1 - A'_0 \\
h'_2 = e'_2 - B'_1 & f'_2 = g'_2 - A'_1 \\
H_0 = S_0 - \kappa V''_0 & \\
\kappa = \frac{2\pi}{\lambda} &
\end{array}\right\} \quad (22)$$

$$\left.\begin{array}{ll}
a'_0 = \int_{-L}^{+L} y_0 \cos\frac{2\pi x}{\lambda}\, dx & b'_0 = \int_{-L}^{+L} y_0 \sin\frac{2\pi x}{\lambda}\, dx \\
a'_1 = \int_{-L}^{+L} y_0\, x \cos\frac{2\pi x}{\lambda}\, dx & b'_1 = \int_{-L}^{+L} y_0\, x \sin\frac{2\pi x}{\lambda}\, dx \\
a'_2 = \int_{-L}^{+L} y_0\, x^2 \cos\frac{2\pi x}{\lambda}\, dx & b'_2 = \int_{-L}^{+L} y_0\, x^2 \sin\frac{2\pi x}{\lambda}\, dx \\
S_0 = \int_{-L}^{+L} y_0\, dx & I_0 = \int_{-L}^{+L} y_0\, x^2\, dx \\
V_0 = \int_{-L}^{+L} dx \int_0^h y\, dz & V'_0 = \int_{-L}^{+L} dx \int_0^h e^{-\kappa z}\, y\, dz \\
\multicolumn{2}{c}{V''_0 = \int_{-L}^{+L} dx \int_0^h e^{-2\kappa z}\, y\, dz} \\
A'_0 = \int_{-L}^{+L} \cos\frac{2\pi x}{\lambda}\, dx \int_0^h e^{-\kappa z}\, y\, dz\,; & B'_0 = \int_{-L}^{+L} \sin\frac{2\pi x}{\lambda}\, dx \int_0^h e^{-\kappa z}\, y\, dz \\
A'_1 = \int_{-L}^{+L} x \cos\frac{2\pi x}{\lambda}\, dx \int_0^h e^{-\kappa z}\, y\, dz\,; & B'_1 = \int_{-L}^{+L} x \sin\frac{2\pi x}{\lambda}\, dx \int_0^h e^{-\kappa z}\, y\, dz \\
C'_0 = \int_{-L}^{+L} \cos\frac{2\pi x}{\lambda}\, dx \int_0^h z\, e^{-\kappa z}\, y\, dz\,; & D'_0 = \int_{-L}^{+L} \sin\frac{2\pi x}{\lambda}\, dx \int_0^h z\, e^{-\kappa z}\, y\, dz \\
C'_1 = \int_{-L}^{+L} x \cos\frac{2\pi x}{\lambda}\, dx \int_0^h z\, e^{-\kappa z}\, y\, dz\,; & D'_1 = \int_{-L}^{+L} \sin\frac{2\pi x}{\lambda}\, dx \int_0^h z\, e^{-\kappa z}\, y\, dz
\end{array}\right\} \quad (23)$$

All these integrals are immediately calculable from data taken from the drawings of the ship, and, as we show in the numerical example, this calculation, if properly made, is a very simple one.

§ 7. As persons acquainted with physical astronomy would remark at a single glance, the analogy of the equations obtained with those of the disturbed motion of heavenly bodies, also the method of integration of the equations (20) and (21) must be that which is used in celestial mechanics. It is the method of successive approximations explained by Laplace in Chap. V. of Vol. I. of the "Mécanique Céleste," or by Sir J. Herschel in the article "Physical Astronomy" of the "Encyclopædia Metropolitana."

This method consists in the following process: First, make $a = 0$, then the equations become exactly integrable in finite terms, the result presents the first approximation. Then substitute in the right hand sides of the given equations for ζ and θ their first approximation, and retain only the terms containing the first power of a. The right hand side becomes then a known function of the time t. Integrate the equation obtained again; the values found for ζ and θ will represent the second approximation, and so on.

The numerical example shows the extreme convergence of the series so obtained.

§ 8. On establishing all the above formulæ, we have supposed the ship at rest, directed at right angles to the crest of the waves, the bow turned in the way of their motion. What alterations must be made if the ship is steaming with a given velocity against or with the waves? To answer this question we must return to the equations (1) and (2) of the wave motion, viz.—

$$x - a = r e^{-\frac{2\pi c}{\lambda}} \sin 2\pi \left(\frac{a}{\lambda} - \frac{t}{\tau}\right) \quad . \; . \; . \; . \qquad (1)$$

$$z - c = r e^{-\frac{2\pi c}{\lambda}} \cos 2\pi \left(\frac{a}{\lambda} - \frac{t}{\tau}\right) \quad . \; . \; . \; . \qquad (2)$$

If the ship is steaming with the velocity v in the same direction as the wave, then the absolute co-ordinate x of that particle whose co-ordinate relatively to the ship is x_1, at the moment t, will be—

$$x = x_1 + vt,$$

instead of $x = x_1$, as it was for the case of rest; the co-ordinate z remains unchanged.

Then equation (1) becomes—

$$x_1 + v\,t - a = r e^{-\frac{2\pi c}{\lambda}} \sin 2\pi \left(\frac{a}{\lambda} - \frac{t}{\tau}\right) \quad . \; . \; . \; . \qquad (24)$$

or,

$$\frac{2\pi a}{\lambda} - \frac{2\pi t}{\tau} = \frac{2\pi x_1}{\lambda} - 2\pi\left(\frac{1}{\tau} - \frac{v}{\lambda}\right) - \frac{2\pi r}{\lambda} e^{-\frac{2\pi c}{\lambda}} \sin 2\pi \left(\frac{a}{\lambda} - \frac{t}{\tau}\right) \quad . \; . \; . \; . \qquad (25)$$

This being compared with equation (1′) that in order to pass to the now considered case, we must in the formulæ (12), (13), and in the following ones, replace the true period of the wave τ by the apparent one τ_1, determined by the equation—

$$\frac{1}{\tau_1} = \frac{1}{\tau} - \frac{v}{\lambda} \qquad (26)$$

If the ship runs against the waves, the apparent period is to be calculated by the formula—

$$\frac{1}{\tau_1} = \frac{1}{\tau} + \frac{v}{\lambda} \tag{27}$$

and, as the bow is now directed in the sense of the negative x axis, $+x$ must be changed into $(-x)$ in all the integrals a'_0, b'_0, A'_0 . . . . D'_1, &c. ; thus all these integrals which bear upon an odd function of x change their sign, and those which bear upon an even one retain it.

Examining closer we shall observe that, to obtain the equation for this case it is only necessary to substitute $(-t)$ for t in all the terms of the right parts of the differential equations (20), (21).

§ 9. On establishing our formulæ we have assumed the form of the ship to be cylindrical close to her L.W.L.; it is perfectly true for the middle body, but not applicable to the bow and stern portions. A correction is necessary—how is it to be made? The approximate positions of the ship on the wave being determined by the previous calculation, we compute directly, for a sufficient number of instants distributed at equal intervals for the whole period τ, the corresponding values of the volume v, contained between the ship's L.W.L. and the corresponding momentary position of the wave and the moments M_v of these volumes.

The exact expression of the said volume v is—

$$v = \int_{-L}^{+L} d\,x \int_{z_1}^{\zeta + \theta x} y\, d\,z, \tag{28}$$

and the approximation as used above was—

$$v = S_0\,\zeta - r\,a'_0 \cos\frac{2\,\pi\,t}{\tau} - r\,b'_0 \sin\frac{2\pi\,t}{\tau} + \ldots . \tag{29}$$

Let t , t , t . . . . t_{n-1} be n equidistant instants, as for example: 0, $\frac{1}{n}\tau$, $\frac{2}{n}\tau$, ... $\frac{n-1}{n}\tau$, and ζ_0, θ_0, ζ_1, θ_1, ... ζ_{n-1}, θ_{n-1}, the corresponding values of ζ and θ at these instants calculated by the first approximation. Then calculate by the formula (28) the corresponding values of v, let them be v_0, v_1, ... v_{n-1}. As ζ and θ are periodical functions of the time t, having the period τ, v can be expanded in the following simple harmonic series—

$$v = S_0\,\zeta - r\,\alpha'_0 \cos\frac{2\,\pi\,t}{\tau} - r\,\beta'_0 \sin\frac{2\,\pi\,t}{\tau} - \ldots . \tag{30}$$

the co-efficients α'_0, β'_0, ... &c., can be determined by the following system of equations :—

$$\left.\begin{aligned}
v_0 &= S_0\,\zeta_0 - r\,\alpha'_0 \cos\frac{2\,\pi\,t_0}{\tau} - r\,\beta'_0 \sin\frac{2\,\pi\,t_0}{\tau} + \ldots . \\
v_1 &= S_0\,\zeta_1 - r\,\alpha'_0 \cos\frac{2\,\pi\,t_1}{\tau} - r\,\beta'_0 \sin\frac{2\,\pi\,t_1}{\tau} + \ldots . \\
&\ldots\ldots\ldots\ldots\ldots\ldots \\
v_{n-1} &= S_0\,\zeta_{n-1} - r\,\alpha'_0 \cos\frac{2\,\pi\,t_{n-1}}{\tau} - r\,\beta'_0 \sin\frac{2\,\pi\,t_{n-1}}{\tau} + \ldots .
\end{aligned}\right\} \tag{31}$$

the method of solving such equations and the auxiliary tables, therefore, are to be found in the "Admiralty Manual of the Deviation of Compasses," by Arch. Smith and J. Evans.

The required corrections in the values of a' and b' , &c., are then—

$$\left.\begin{aligned}
\Delta\,a'_0 &= \alpha'_0 - a'_0 \\
\Delta\,b'_0 &= \beta'_0 - C'_0 \\
&\text{\&c.}
\end{aligned}\right\} \tag{32}$$

Practically it is quite sufficient to take $n = 4$, then

$$\left.\begin{aligned} \alpha'_0 &= \frac{(S_0\,\zeta_0 - v_0) - (S_0\,\zeta_2 - v_2)}{2\,r} \\ \beta'_0 &= \frac{(S_0\,\zeta_1 - v_1) - (S_0\,\zeta_3 - v_3)}{2\,r} \end{aligned}\right\} \tag{33}$$

Quite in the same manner and using the evident analogous notation, we obtain for the corrections of the moments—

$$\left.\begin{aligned} \Delta\,\alpha'_1 &= \alpha'_1 - \alpha'_1 \\ \Delta\,b'_1 &= \beta'_1 - b'_1 \end{aligned}\right\} \tag{34}$$

&c.,

where, taking $n = 4$, we have—

$$\left.\begin{aligned} \alpha'_1 &= \frac{(I_0\,\theta_0 - M_0) - (I_0\,\theta_2 - M_2)}{2\,r} \\ \beta'_1 &= \frac{(I_0\,\theta_1 - M_1) - (I_0\,\theta_3 - M_3)}{2\,r} \end{aligned}\right\} \tag{35}$$

M_0, M_1, M_2, M_3, designating the moments of the volume contained between the L.W.L. and the surface of the wave at the instants

$$t_0 = 0,\ t_1 = \frac{1}{4}\tau,\ t_2 = \frac{1}{2}\tau,\ t_3 = \frac{3}{4}\tau.$$

The details of calculation are shown in the numerical examples.

This correction is, in most cases, practically insignificant, it must only be made if it is proposed to examine the influence of the form of the ship on her pitching, or the influence of the distribution of loads and of the trim.

§ 10. The laws of the resistance of water were assumed with a very rough approximation; it is necessary to show that even large errors in the values of the co-efficients of resistance are of no importance. The principal effect of resistance being to extinguish the "proper" oscillations of the ship, and to leave almost unchanged her "forced" oscillations. In the single case of synchronism, the resistance must be calculated more exactly.

A numerical example suffices to make it clearer. The oscillations of a ship on taking the co-efficients of resistance as for a plane are expressed by the following two equations—

$$\zeta = 0^m{\cdot}26 + 1^m{\cdot}02 \cos\frac{2\,\pi\,t}{9} - 0^m{\cdot}15 \sin\frac{2\,\pi\,t}{9}$$

$$\theta = -\,0^\circ\,22' \cos\frac{2\,\pi\,t}{9} + 5^\circ\,24' \sin\frac{2\,\pi\,t}{9}$$

If the resistance is one-half the above value, ζ and θ are—

$$\zeta = 0^m{\cdot}26 + 1^m{\cdot}02 \cos\frac{2\,\pi\,t}{9} - 0^m{\cdot}16 \sin\frac{2\,\pi\,t}{9}$$

$$\theta = -\,0^\circ\,4' \cos\frac{2\,\pi\,t}{9} + 5^\circ\,23' \sin\frac{2\,\pi\,t}{9}$$

If resistance is one-fifth of that for a plane—

$$\zeta = 0{\cdot}26 + 1{\cdot}02 \cos \frac{2\pi t}{9} - 0{\cdot}17 \sin \frac{2\pi t}{9}$$

$$\theta = +\ 0^\circ\, 6' \cos \frac{2\pi t}{9} + 5^\circ\, 22' \sin \frac{2\pi t}{9}$$

If one-tenth—

$$\zeta = 0{\cdot}26 + 1{\cdot}02 \cos \frac{2\pi t}{9} - 0{\cdot}18 \sin \frac{2\pi t}{9}$$

$$\theta = +\ 0^\circ\, 12' \cos \frac{2\pi t}{9} + 5^\circ\, 22' \sin \frac{2\pi t}{9}$$

If no resistance at all—

$$\zeta = 0{\cdot}26 + 1{\cdot}02 \cos \frac{2\pi t}{9} - 0{\cdot}18 \sin \frac{2\pi t}{9}$$

$$\theta = 0^\circ\, 12' \cos \frac{2\pi t}{9} + 5^\circ\, 22' \sin \frac{2\pi t}{9}$$

In all these cases practically the pitching and vertical oscillations are the same.

It is not difficult to examine theoretically the general case of resistance expressed by the formula $R = a\,v + b\,v^2$, consisting of two terms, the first proportional to the simple velocity, the second to the square of the velocity, but the calculations are a little complicated.

§ 11. From the theory now submitted we see that hence the pitching motion of a ship can be closely calculated when her drawings are given, the influence on her nautical properties of the forms of her bow, her stern, of the trim, the maximum velocity attainable on large waves, the bending moments, &c., may be obtained no longer by "rule of thumb," but by a rigorous mathematical investigation.

§ 12. We have treated in this paper only the case of pure pitching; pure rolling can be treated in the same manner, we have only to interchange the letters x and y between them, and to observe that the resistance of water is very much reduced, so that the "proper" oscillations of the ship are no longer extinguished.

If the ship's head is oblique in relation to the crests of the waves, there is rolling combined with pitching; the angle of rolling being often a large one, the strictly mathematical treatment of the problem requires the use of elliptic functions, and I am afraid that there is already too much mathematics in my paper to introduce into it elliptic functions, this bugbear for practical men. I shall delay it to another time, when I shall still have the honour to submit to the Institution of Naval Architects the theory of rolling and pitching combined, properly illustrated by numerical examples, and diagrams which, perhaps, will reconcile even the practical man to a small dose of elliptic functions, this greatest mathematical gain of our century.

APPENDIX II.

Numerical Examples and Calculations.

Following Newton's words "non præcepta sed exemplo," we give a numerical example to illustrate our theory.

All the calculations are made in a fully detailed manner, not a single figure has been written anywhere apart.

To form the differential equations of the vertical oscillations, and of the pitching of the ship, it is necessary to calculate the numerical values of several definite integrals. It could be performed by Simpson's rule, but the calculation is simpler and more symmetrical, if, instead of Simpson's, the late Professor Tchebysheff's rule be used.

This rule is expressed as follows:—To compute the value of the definite integral $\int_{-L}^{+L} f(x)\,dx$, calculate the values of the subintegral function corresponding to the values of the abscissæ x shown in the Table here subjoined, and multiply the mean value of the functions by the difference 2 L of the limits of the integral. Thus—

$$\int_{-L}^{+L} f(x)\,d\,x = \frac{2\,L}{n}\left[f(x_1) + f(x_2) + \ . \ . \ . \ . \ + f(x_n)\right].$$

TABLE I.

Values of Tchebysheff's Abscissæ.

x \ n	5	6	7	9
x_1	0·8325 . L	0·8662 . L	0·88386 . L	0·91159 . L
x_2	0·3745 . L	0·4225 . L	0·52966 . L	0·60102 . L
x_3	0·0000	0·2666 . L	0·32391 . L	0·52876 . L
x_4	−0·3745 . L	−0·2666 . L	0·00000	0·16791 . L
x_5	−0·8325 . L	−0·4225 . L	−0·32391 . L	0·00000
x_6	—	−0·8662 . L	−0·52966 . L	−0·16791 . L
x_7	—	—	−0·88386 . L	−0·52876 . L
x_8	—	—	—	−0·60102 . L
x_9	—	—	—	−0·91159 . L

For $n = 8$, several of the x values are imaginary.

In my paper, "Nouvelle Méthode de Calcul des Éléments d'une Carène," Bulletin de l'Associat. Tech. Marit., No. 4, 1893, I show the advantages of the use of Tchebysheff's formula for shipbuilding calculations.

In our present case a relative error of 1 to 2 per cent. being of no importance, it is sufficient to take $n = 7$, when the limits are L and − L, the half length of the ship; and $n = 5$, when they are 0 and h, the draught of the ship. Applying this rule, we make the calculations according to the following schedules:—

Calculation of Pitching.

Name of the ship : *Admiral Korniloff.*

Dimensions of the ship ... { Length ... ... $2L = 107^m = 350'$
Beam ... ... $B = 14^m{\cdot}8 = 48'\ 6''$
Draught ... ... $h = 5^m{\cdot}9 = 19'$

Displacement ... ... $V_0 = 5{,}000$ tons.

Elements of the wave ... { Length ... ... $\lambda = 125^m = 420'$
Height ... ... $2r = 5^m = 16'\ 6''$
Period ... ... $\tau = 9^{sec.}$

TABLE II.

Calculation of the Values of a'_0, b'_0, a'_1, b'_1, S_0, I.

Formulæ:

$$a'_0 = \int_{-L}^{+L} y_0 \cos\frac{2\pi x}{\lambda}\, d\,x\,; \quad b'_0 = \int_{-L}^{+L} y_0 \sin\frac{2\pi x}{\lambda}\, d\,x\,; \quad S_0 = \int_{-L}^{+L} y_0\, d\,x$$

$$a'_1 = \int_{-L}^{+L} y_0\, x \cos\frac{2\pi x}{\lambda}\, d\,x\,; \quad b'_1 = \int_{-L}^{+L} y_0\, x \sin\frac{2\pi x}{\lambda}\, d\,x\,; \quad I = \int_{-L}^{+L} y_0\, x^2\, d\,x\,.$$

(See Paper, § 5 ; Appendix, § 6.)

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.
No. of the Cross-Section.	Abscissæ Value x in Metres.	Ordinates y_0 of L.W.L. for the Bow Portions.	Ordinates y_0 of the L.W.L. Stern Portion.	III. + IV.	III. − IV.	$\phi = \frac{2\pi x}{\lambda} = 360^\circ \cdot \frac{x}{\lambda}$	V. cos ϕ	V. sin ϕ	VI. cos ϕ	VI. sin ϕ	X. x	IX. x	$\frac{x^2}{100}$	V. $\frac{x^2}{100}$
1 & 7	47·3	20	* 36	56	−16	136°	− 40·3	38·9	+11·5	−11·1	544	1838	22·37	1,250
2 & 6	28·4	82	102	184	−20	82°	+ 25·6	182·2	− 2·8	−19·8	− 79	5173	8·07	1,485
3 & 5	17·3	102	110	212	− 8	50°	+136·3	162·4	− 5·1	− 6·1	− 86	2770	3·00	636
4	0	111	—	111	111	0°	+111	0	111	0	0	0	0	0
Sums				563			233·2			−37·0	379	9,781		3,371

* All ordinates here and elsewhere are taken in millimetres from the original drawings. As the scale is $15\,\frac{m}{m} = 1^m$, the values of the ordinates must be divided by 15 to be reduced in metres.

The constant factor by which these several sums must be multiplied to obtain the value of the integrals is $\frac{1}{15} \cdot \frac{107}{7} \cdot 2 = 2{\cdot}04$ (here $\frac{1}{15}$ proceeds from the scale, 107^m is the length (2 L) of the ship; $7 = n$ is the number of ordinates, 2 is introduced because in the integrals y_0 are the whole breadths of the L.W.L. at different cross-sections, but from drawings are taken only half breadths). Thus—

$$S_0 = 563 \times 2{\cdot}04 = 1{\cdot}149 \square m. \quad I = 337{,}100 \times 2{\cdot}04 = 688{,}000.$$

$$a'_0 = 233{\cdot}2 \times 2{\cdot}04 = 475\,;\ b'_0 = -37 \times 2{\cdot}04 = -75\,;\ a'_1 = 379 \times 2{\cdot}04 = 774\,;\ b'_1 = 9{,}781 \times 2{\cdot}04 = 19{,}950.$$

TABLE III.

CALCULATION OF THE DISPLACEMENT V_0.

No. of the W. L. \ No. of the Cross-Section.	Bow Part.				Stern Part.			Sum.
	1	2	3	4 ⊠	5	6	7	
I. ($z_1 = 0^m{\cdot}49$) ...	17·3	79·0	102·0	111·0	110·0	101·5	26·0	546·8
II. ($z_2 = 1{\cdot}85$)... ...	13·0	73·0	99·0	108·5	106·0	95·5	7·0	502·0
III. ($z_3 = 2{\cdot}95$)... ...	8·5	67·5	94·5	102·5	97·5	82·0	3·5	453·0
IV. ($z_4 = 4{\cdot}05$)... ...	4·0	48·0	82·0	88·0	79·0	57·0	3·0	361·0
V. ($z_5 = 5{\cdot}41$)... ...	1·0	12·0	41·0	41·0	28·5	18·0	3·0	144·5
Sums	43·8	276·5	418·5	451·0	421·0	354·0	42·5	2,007·3

The constant factor by which the general sum is to be multiplied to obtain the corresponding value of one of the double integrals, such as the displacement, is: $\frac{1}{15} \cdot \frac{1}{7} \cdot \frac{1}{5} \cdot 107 \,.\, 5{\cdot}9 \,.\, 2 = 2{\cdot}42$ (here the factors proceed: $\frac{1}{15}$ from the scale, $\frac{1}{7}$ and $\frac{1}{5}$ from the number of sectinos, 107^m is the length of the ship, 5·9 her draught). Thus—

$$\text{Displacement}: V_0 = 2{,}007{\cdot}3 \times 2{\cdot}42 = 4{,}890^{c.m} = 5{,}010^t.$$

TABLE IV.—Calculation of the Reduced Displacement.

$$V'_0 = \int_{-L}^{+L} d\,x \int_0^h y \,.\, e^{-\frac{2\pi z}{\lambda}} \,.\, d\,z. \quad \text{(See Appendix, § 6.)}$$

No. of W.L.	$\frac{2\pi z}{\lambda}$	Factor of Reduction. $e^{-\frac{2\pi z}{\lambda}}$	Bow Part. Reduced 1	2	3	4	Stern Part. Ordinates. 5	6	7	Sum.
I.	0·024	$1-\frac{1}{40}$	17	77	100	108	108	99	25	534
II.	0·092	$1-\frac{1}{11}$	12	66	90	98	97	87	6	456
III.	0·147	$1-\frac{1}{7}$	7	55	81	85	83	70	3	384
IV.	0·202	$1-\frac{1}{5}$	3	38	66	70	63	46	2	288
V.	0·270	$1-\frac{1}{4}$	1	9	31	31	21	13	2	108
Sums		$\sigma=$	40	245	368	392	372	315	38	1,770

Once reduced, displacement $V'_0 = 1{,}770 \,.\, 2{\cdot}42 = 4{,}257$ cub. met. Reduction $R = V_0 - V' = 4{,}890 - 4{,}253 = 633$. Twice reduced, displacement $V''_0 = V'_0 - R = 4{,}257 - 633 = 3{,}624$ cub. met.

TABLE V.—Calculation of the Values of A'_0 and B'_0.

$$A'_0 = \int_{-L}^{+L} d\,x \int_0^h e^{-\frac{2\pi z}{\lambda}}\, y \cos\frac{2\pi x}{\lambda}\, d\,z\,; \qquad B'_0 = \int_{-L}^{+L} d\,x \int_0^h e^{-\frac{2\pi z}{\lambda}}\, y \sin\frac{2\pi x}{\lambda}\, d\,z \quad \text{(Appendix, § 6.)}$$

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
No. of Cross-Section.	Abscissa x	Sums σ, Table IV. Bow Part.	Sums σ, Table IV. Stern Part.	III. + IV.	III. − IV.	V. cos ϕ $\left(\phi = \frac{2\pi x}{\lambda}\right)$	V. sin ϕ $\left(\phi = \frac{2\pi x}{\lambda}\right)$	VI. cos ϕ	VI. sin ϕ
1 & 7	47·3	40	38	78	+ 2	− 56·1	54·2	−1·5	+ 1·5
2 & 6	28·4	245	315	560	−70	+ 78	555	−9·7	−62·3
3 & 5	17·3	368	372	740	− 4	+476	567	−2·6	− 3·1
4	0	392		392	392	+392	0	392	0
						890			−70·9

$A'_0 = 890 \times 2{\cdot}42 = 2{,}154.$ $\qquad B'_0 = -70{\cdot}9 \times 2{\cdot}42 = -171.$

TABLE VI.

Calculation of the Values of C'_0 and D'_0.

$$C'_0 = \int_{-L}^{+L} d\,x \int_0 z\,e^{-\frac{2\pi z}{\lambda}}\, y \cos\frac{2\pi x}{\lambda}\, d\,z\,; \qquad D'_0 = \int_{-L}^{+L} d\,x \int_0^h z\,e^{-\frac{2\pi z}{\lambda}}\, y \sin\frac{2\pi x}{\lambda}\, d\,z.$$

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.	
No. of W.L.	Differences of Ordinates of W.L.							VIII. + II.	VII. + III.	VI. + IV.	V.	II. − VIII.	III. − VII.	IV. − VI.	Factors $z - \frac{h}{2}$
	Bow Part.			⊠	Stern Part.										
	1	2	3	4	5	6	7								
I. − V.	16	68	69	77	87	86	23	39	154	156	77	−7	−18	−18	−2·46
II. − IV.	9	28	24	28	34	41	4	13	69	58	28	+5	−13	−10	−1·10
								Products by the Factors $\left(z - \frac{h}{2}\right)$							
								− 96	−380	−385	−190	+17	+45	+45	
								− 14	− 76	− 64	− 31	− 5	+14	+11	
							Sums ... ... σ_1	−110	−456	−449	−221	+12	+59	+56	
							$\sigma_1 \cos\frac{2\pi x}{\lambda}$	+ 79	− 64	−289	−221	—	—	—	
							$\sigma_1 \sin\frac{2\pi x}{\lambda}$	—	—	—	—	8·3	58·4	42·9	

$$S_1 = \Sigma\,\sigma_1 \cos\frac{2\pi x}{\lambda} = -495\,; \qquad S_2 = \Sigma\,\sigma_1 \sin\frac{2\pi x}{\lambda} = +109{\cdot}6.$$

$$C'_0 = A'_0 \,.\, \frac{h}{2} + S_1 \;\; 2{\cdot}42 = (890 \times 2{\cdot}95 - 495) \times 2{\cdot}42 = 5{,}155.$$

$$D'_0 = B'_0 \,.\, \frac{h}{2} + S_2 \,.\, 2{\cdot}42 = (-70{\cdot}9 \times 2{\cdot}95 + 109{\cdot}6) \times 2\;42 = -242.$$

Approximate Calculation of the Ship's Moment of Inertia K.

If the loads were distributed on the ship in an ideally perfect manner, that is, if the weight of the part of the ship's hull and of all contained in it between any two cross-sections be equal to displacement of the corresponding stratum, it is evident that the moment of inertia of the ship would be very nearly equal to that of her displacement. The distribution of loads being never ideally perfect, it is necessary to add a correction to the value of the moment of inertia of the ship's displacement, according to the real distribution of loads.

TABLE VII.

MOMENT OF INERTIA OF THE SHIP'S DISPLACEMENT.

I.	II.	III.	IV.	V.	VI.
No. of the Cross-Sections.	Sums of Ordinates (Table III.) Bow Part.	Sums of Ordinates (Table III.) Stern Part.	II. & III.	$\frac{x^2}{100}$	IV. $\frac{x^2}{100}$
1 & 7	43·8	42·5	86·3	22·37	1,890
2 & 6	276·5	354·0	630·5	8·07	5,120
3 & 5	418·5	421·0	839·5	3·00	2,510
4	451·0		451·0	0	0
					9,520

$$g\,K = 952{,}000 \times 2{\cdot}42 = 2{,}300{,}000$$
$$\text{Correction for loads} = \underline{\;820{,}000\;}$$
$$3{,}120{,}000$$
$$K = 318{,}000\,.\,t\,.\,(\text{met.})^2.$$

APPROXIMATIVE CALCULATION OF THE RESISTANCE OF WATER.

To compute approximate values of $2\,N$ and $2\,N_1$, the co-efficients of resistance of water, we observe that the velocity of the vertical motion of the ship $\left(\frac{d\,\zeta}{d\,t}\right)$ is less than $0^m{\cdot}7$ per second (this velocity would be, if there were no resistance), and the resistance of the ship's surface is less than that of the plane of her L.W.L. But the resistance of a plane is approximately expressed by the formula: $R = 0.06\,S\,v^2$ (resistance, R in tons, S in square metres, v in metres per second). Thus the co-efficient $2\,N \leqq \frac{0{\cdot}06\,.\,(0{\cdot}7)^2.\,S}{0{\cdot}7}$ [See § 5 (1.)], thus $2\,N \leqq 0{\cdot}04\,S$, or $2\,N \leqq 47$.

Quite in the same manner, observing that for the pitching the vertical velocity of the different elements of the ship's skin are less at 2^m per second, we obtain that the moment of resistance $M \leqq \kappa\,\frac{d\,\theta}{d\,t}$, where $\kappa = \frac{0{\cdot}06\,.\,2^2.}{2}\,.\,I$, I being the moment of inertia of the area of the ship's L.W.L. Thus $2\,N_1 \leqq 0{\cdot}12\,I$.

DIFFERENTIAL EQUATIONS OF THE PITCHING AND OF THE VERTICAL OSCILLATIONS OF THE SHIP, AND THEIR INTEGRATIONS.

All the preparatory calculations being performed, we can proceed to write down the differential equations of the ship's motion. These equations are given in the Appendix (§ 6), formulæ (20), ond

(21), and to write them down it is only necessary to compute the values of the co-efficients m'_0, n'_0, &c. We have—

$$m'_0 = a'_0 - \frac{2\pi}{\lambda} A'_0 = 475 - \frac{1}{20} 2{,}154 = 367$$

$$n'_0 = b'_0 - \frac{2\pi}{\lambda} B'_0 = -75 + \frac{1}{20} 171 = -66$$

$$H_0 = S_0 - \frac{2\pi}{\lambda} V''_0 = 1{,}149 - \frac{1}{20} 3{,}624 = 968$$

$$e'_1 = a'_1 + \frac{2\pi}{\lambda} D'_0 = 774 - \frac{1}{20} 242 = 762$$

$$g'_1 = b'_1 - \frac{2\pi}{\lambda} C'_0 = 19{,}950 - \frac{1}{20} 5{,}155 = 19{,}690$$

$$\frac{P}{g} = q \,.\, \frac{V_0}{g} = 9 \,.\, 498{\cdot}4.*$$

Substituting these values, and remarking that $r = 2^m{\cdot}5$ we have—

$$498{\cdot}4 \frac{d^2\zeta}{dt^2} + 47 \frac{d\zeta}{dt} + 1{,}149\,\zeta = 303 + 918 \cos\frac{2\pi t}{\tau} - 165 \sin\frac{2\pi t}{\tau} + \ldots.$$

$$318{,}000 \frac{d^2\theta}{dt^2} + 82{,}560 \frac{d\theta}{dt} + 680{,}000\,\theta = 1{,}905 \cos\frac{2\pi t}{\tau} + 49{,}500 \sin\frac{2\pi t}{\tau} + \ldots.$$

Or, dividing the first of these equations by 498·4 and the second by 318,000, and reducing the absolute angular measure to degrees and minutes, we obtain—

$$\frac{d^2\zeta}{dt^2} + 0{\cdot}094 \frac{d\zeta}{dt} + 2{\cdot}30\,\zeta = 0{\cdot}61 + 1{\cdot}84 \cos\frac{2\pi t}{\tau} - 0{\cdot}3 \sin\frac{2\pi t}{\tau} \qquad (1)$$

$$\frac{d^2\theta}{dt^2} + 0{\cdot}26 \frac{d\theta}{dt} + 2{\cdot}16\,\theta = 0{\cdot}006 \cos\frac{2\pi t}{\tau} + 0{\cdot}1557 \sin\frac{2\pi t}{\tau} \qquad (2)$$

$$= 0^\circ\, 21' \cos\frac{2\pi t}{\tau} + 8^\circ\, 57' \sin\frac{2\pi t}{\tau}.$$

It being necessary to obtain the first approximation, the terms containing the factor a are not written. The general integrals of these linear equations are—

$$\zeta = e^{-0{\cdot}047\,t} \left\{ C_1 \cos n_1 t + C_2 \sin n_1 t \right\} + A \cos\frac{2\pi t}{\tau} + B \sin\frac{2\pi t}{\tau} + \frac{0{\cdot}61}{2{\cdot}30} \qquad (3)$$

$$\theta = e^{-0{\cdot}13\,t} \left\{ C_3 \cos n_2 t + C_4 \sin n_2 t \right\} + A_1 \cos\frac{2\pi t}{\tau} + B_1 \sin\frac{2\pi t}{\tau} \qquad (4)$$

where C_1, C_2, C_3, C_4 are the arbitrary constants, $n_1 = \sqrt{2{\cdot}30 - (0{\cdot}047)^2}$, and $n_2 = \sqrt{2{\cdot}16 - (0{\cdot}26)^2}$, A, B and A_1, B_1, undetermined co-efficients which are given by the following equations :—

$$\left.\begin{aligned} \left[2{\cdot}30 - \left(\frac{2\pi}{\tau}\right)^2\right] A + 0{\cdot}094 \,.\, \frac{2\pi}{\tau} B &= 1{\cdot}84 \\ -0{\cdot}094 \,.\, \frac{2\pi}{\tau} A + \left[2{\cdot}30 - \left(\frac{2\pi}{\tau}\right)^2\right] &= -0{\cdot}3, \end{aligned}\right\} \qquad (5)$$

* $q = g\,\rho$ is the weight of a cubic metre of sea-water. All terms being multiplied by q, it falls out of the equations.

and

$$\left.\begin{aligned}\left[2{\cdot}16-\left(\frac{2\pi}{\tau}\right)^2\right]A_1+0{\cdot}26\frac{2\pi}{\tau}B_1&=0{\cdot}006=0^\circ\,21'\\ -0{\cdot}26\,.\frac{2\pi}{\tau}A_1+\left[2{\cdot}16-\left(\frac{2\pi}{\tau}\right)^2\right]&=0{\cdot}1557=8^\circ\,57'\end{aligned}\right\}\quad(6)$$

For our case the period of the wave $\tau = 9^s$ and the above equations give—

$$A = \quad 1^m{\cdot}02\ ;\quad B = -\,0^m{\cdot}15$$
$$A_1 = -\,0^\circ\,22'\,;\quad B_1 = +\,5^\circ\,24'$$

The terms with the arbitrary constants containing the exponential factors $e^{-0{\cdot}047t}$ and $e^{-0{\cdot}13t}$, it is quite useless to determine these constants from the initial conditions, because after a few seconds these terms become negligible. Thus the motion of the ship after several seconds from its beginning, or, so to say, her "permanent motion," will be expressed by the two finite equations—

$$\zeta = 0^m{\cdot}26 + 1^m{\cdot}02\cos\frac{2\pi t}{\tau} - 0{\cdot}15\sin\frac{2\pi t}{\tau}$$
$$\theta = -\,0^\circ\,22'\cos\frac{2\pi t}{\tau} + 5^\circ\,24'\sin\frac{2\pi t}{\tau}.$$

To proceed to the second approximation, it is, in the first instance, necessary to compute the co-efficient expressed by the integrals [(23), Appendix, § 6], and to substitute for ζ and θ the above values.

On making this calculation, we have obtained that the following corrections are to be added to the above values of ζ and θ.

$$\Delta\zeta = 0{\cdot}1 - 0{\cdot}12\cos\frac{4\pi t}{\tau} + 0{\cdot}03\sin\frac{4\pi t}{\tau}$$
$$\Delta\theta = 0^\circ\,5' + 0^\circ\,0'\,13''\cos\frac{2\pi t}{\tau} - 0^\circ\,0'\,35''\sin\frac{2\pi t}{\tau} + 0^\circ\,4'\cos\frac{4\pi t}{\tau} - 0{\cdot}7'\sin\frac{4\pi t}{\tau} + \ldots.$$

the co-efficient in the following terms being also few minutes and seconds. This result shows clearly that the first approximation is practically quite sufficient.

Influence of the Ship's Own Velocity of Steaming.

As explained in the Appendix (§ 8), to take the ship's own velocity into account, it is necessary to substitute for τ the apparent period τ_1 of the wave, and to make the necessary changes of sign accordingly as to the direction of the positive x axis.

Thus, to calculate, for instance, the cases of pitching of the ship under consideration, but steaming 12·5 knots, we have (12·5 κ, being closely equal to $6^m{\cdot}25$ per second).

If the ship steams with the waves: $\dfrac{1}{\tau_1} = \dfrac{1}{\tau} - \dfrac{v}{\lambda} = \dfrac{1}{9} - \dfrac{6{\cdot}25}{125} = \dfrac{11}{180}$

thus $\tau_1 = 16^s$.

If the ship steams against the waves: $\dfrac{1}{\tau_1} = \dfrac{1}{\tau} + \dfrac{v}{\lambda} = \dfrac{1}{9} + \dfrac{6{\cdot}25}{125} = \dfrac{29}{180}$

$\tau_1 = 6^s{\cdot}2.$

Substituting these values in the equations (1) to (6), we obtain—

$$\left.\begin{aligned}\zeta &= 0{\cdot}26 + 0{\cdot}86\cos\frac{2\pi t}{16} - 0{\cdot}17\sin\frac{2\pi t}{16}\\ \theta &= -\,0^\circ\,3'\cos\frac{2\pi t}{16} + 4^\circ\,28'\sin\frac{2\pi t}{16} = 4^\circ\,28'\sin\left(\frac{2\pi t}{16} - 1^\circ\right)\end{aligned}\right\}\quad(7)$$

when the ship is steaming with the waves, and—

$$\left.\begin{aligned} \zeta &= 0{\cdot}26 + 1{\cdot}51 \cos\frac{2\pi t}{6{\cdot}2} + 0{\cdot}39 \sin\frac{2\pi t}{6{\cdot}2} \\ \theta &= -\,2^\circ 19' \cos\frac{2\pi t}{6{\cdot}2} + 7^\circ 40' \sin\frac{2\pi t}{6{\cdot}2} = 8^\circ 0' \sin\left(\frac{2\pi t}{6{\cdot}2} - 17^\circ\right) \end{aligned}\right\} \quad (8)$$

when the ship steams against the waves.

Correction for Ship's Form.

It is explained in the Appendix (§ 9) how to take the non-cylindricity of the ship's forms into account, the above results being computed, assuming the ship's skin at right angles to the plane of of her L.W.L. A numerical example of such calculation is here given—

TABLE VIII.

Calculation of v_0 and M_0.

$t = 0$ $\qquad \zeta_0 = 0{\cdot}26 + 1{\cdot}02 = 1{\cdot}28. \qquad \theta_0 = -\,0^\circ\,22' = -\,0{\cdot}006.$

$$z_1 = 0{\cdot}16 + 2{\cdot}5 \cos\frac{2\pi x}{\lambda} - 0{\cdot}16 \cos\frac{4\pi x}{\lambda}$$

$$u = \zeta_0 + \theta_0 x - z_1 = 1{\cdot}12 - 0{\cdot}006\,x - 2{\cdot}5 \cos\frac{2\pi x}{\lambda} + 0{\cdot}16 \cos\frac{4\pi x}{\lambda}$$

$$v_0 = \int_{-L}^{+L} d\,x \int_0^u y\,d\,z. \qquad M_0 = \int_{-L}^{+L} x\,d\,x \int_0^u y\,d\,z.$$

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.
No. of the Cross-Section.	Abscissa x.	$\phi = \frac{2\pi x}{\lambda}$	$2\phi = \frac{4\pi x}{\lambda}$	$-\theta_0 . x = -0{\cdot}006 . x$	$-2{\cdot}5 . \cos\phi$	$+0{\cdot}16 \cos 2\phi$	$u = 1{\cdot}12 + \text{V.} + \text{VI.} + \text{VII.}$	Ordinate y_0 at the L.W.L.	Ordinate y_1 at the Surface of Wave.	$\frac{1}{2}(y_0 + y_1)$.	Immersed Areas $= \frac{1}{2}(y_0 + y_1) . u$.	Immersed Areas of the Stern Part.	XII. − XIII.	Moments of Areas = XIV. x.
1	47·3	136°	272°	−0·28	+1·80	0·0	+2·64	20	28	24	+ 63	189	−126	−5,960
2	28·4	82°	164°	−0·17	−0·35	−0·15	+0·45	82	82	82	+ 37	80	− 43	−1,221
3	17·3	50°	100°	−0·10	−1·61	−0·03	−0·62	102	102	102	− 63	−45	− 18	− 311
4	0·0	0°	0°	0	−2·50	+0·16	−1·22	111	110	110	−132			
5	−17·3	− 50°	−100°	+0·10	−1·61	−0·03	−0·42	110	108	109	− 45			
6	−28·4	− 82°	−164°	+0·17	−0·35	−0·15	+0·79	102	102	102	+ 80			
7	−47·3	− 136°	−272°	+0·28	+1·80	0·0	+3·20	36	82	59	+189			
							Sum	...	...		+129			−7,492

Immersed volume $v_0 = 129 \times 2{\cdot}04 = 263\,cub.\,m.$ $\qquad S_0\,\zeta_0 = 1{,}149 \times 1{\cdot}28 = 1{,}370.$

Moment ... ... $M_0 = -\,7{,}492 \times 2{\cdot}04 = -\,15{,}280.$ $\qquad I_0\,\theta_0 = -\,688{,}000 \times 0{\cdot}0064 = -\,4{,}406.$

TABLE IX.

CALCULATION OF v_2 AND M_2 (FOR THE MOMENT $t = \frac{7}{2}$).

$$t = \frac{7}{2} = 4^{s}\cdot 5. \quad \zeta_2 = 0\cdot 26 - 1\cdot 02 = -0\cdot 76\,; \qquad \theta_2 = +0\cdot 006.$$

$$z_1 = 0\cdot 16 + 2\cdot 5 \cos\left(\frac{2\pi x}{\lambda} - \pi\right) - 0\cdot 16\left(\cos\frac{4\pi x}{\lambda} - 2\pi\right)$$

$$u = \zeta_2 + \theta x - z_1 = -0\cdot 92 + \theta x + 2\cdot 5 \cos\frac{2\pi x}{\lambda} + 0\cdot 16 \cos\frac{4\pi x}{\lambda}$$

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.
No. of the Cross-Section.	Abscissa x.	$\varphi = \frac{2\pi x}{\lambda}$	$2\varphi = \frac{4\pi x}{\lambda}$	$\theta x = 0\cdot 006\, x$.	$2\cdot 5 \cos \varphi$.	$0\cdot 16 \cos 2\varphi$.	$u = -0\cdot 92 + \text{V.} + \text{VI.} + \text{VII.}$	Ordinate y_0 of the L.W.L.	Ordinate y_1 at the Surface of Wave.	$\frac{1}{2}(y_0 + y_1)$.	Immersed Areas $= \frac{1}{2}(y_0 + y_1) \cdot u$.	Immersed Areas of the Stern Part.	XII.—XIII.	Moments $=$ XIV. x.
1	47·3	136°	272°	+0·28	−1·80	0	−2·28	20	8	14	− 32	−70	+ 8	378
2	28·4	82°	164°	+0·17	+0·35	−0 15	−0·39	82	79	80	− 32	−74	+42	1,193
3	17·3	50°	100°	+0 10	+1·61	−0·03	+0·92	102	102	102	+ 93	+79	+14	242
4	0	0°	0°	0·00	+2·50	+0·16	+1 90	111	109	110	+209			
5	−17·3	− 50°	−100°	−0·10	+1·61	−0·03	+0·72	110	110	110	+ 79			
6	−28·4	− 82°	−164°	−0·17	+0·35	−0·15	−0·73	102	101	101	− 74			
7	−47·3	−136°	−272°	−0·28	−1·80	0	−2 84	36	113	14(*)	− 40			
							Sum	...	...		+ 213			1,813

Immersed Volume ... $v_2 =$ 213 × 2·04 = 434 c. met.

Moment ... ... $M_2 =$ 1,813 × 2·04 = 3,709.

$S_0 \zeta_2 = -$ 1,149 × 0·76 = − 874

$I\,\theta_2 = +$688,000 × 0·0064 = + 4,406.

TABLE X.

Calculation of the Values of v_1 and M.

$$t = \frac{\tau}{4} = 2''\cdot 25\,; \quad \zeta_1 = 0\cdot 26 - 0\cdot 15 = 0\cdot 09\,; \quad \theta_1 = 5^\circ\, 24' = +\,0\cdot 0943.$$

$$z_1 = 0\cdot 16 + 2\cdot 5 \cos\left(\frac{2\,\pi\,x}{\lambda} - \frac{\pi}{2}\right) - 0\cdot 16 \cos\left(\frac{4\,\pi\,x}{\lambda} - \pi\right); \quad u = -\,0\cdot 07 + \theta\,x.$$

$$u = \zeta_1 + \theta_1\,x - z_1 = -\,0\cdot 07 + 0\cdot 0943\,x - 2\cdot 5 \cos\left(\frac{2\,\pi\,x}{\lambda} - \frac{\pi}{2}\right) + 0\cdot 16 \cos\left(\frac{4\,\pi\,x}{\lambda} - \pi\right).$$

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.
No. of the Cross-Section.	Abscissa x	$\phi = \frac{2\,\pi\,x}{\lambda} - \frac{\pi}{2}$	$\phi = \frac{4\,\pi\,x}{\lambda} - \pi$	$\theta\,x = 0\cdot 0943\,x$.	$2\cdot 5 \cos 2\,\phi$	$0\cdot 16 \cos \phi$	$u = 0\cdot 09 + \text{V.} + \text{VI.} + \text{VII.}$	Ordinate y_0 at the L.W.L.	Ordinate y_1 at the Surface of Wave.	$\frac{1}{2}\,(y_0 + y_1)$.	Immersed Areas.	Immersed Areas of the Stern Part.	XII. − XIII.	Moments.
1	47·3	46°	92°	+4·45	−1·74	0	2·63	20	27	23·5	+62	−39	+101	4,777
2	28 4	− 8°	− 16°	+2·67	−2·48	+0·15	0·27	82	82	82	+22	−11	+ 33	937
3	17·3	− 40°	− 80°	+1·63	−1·92	+0·03	−0·33	102	102	102	−34	+27	− 61	-1,055
4	0	− 90°	−180°	0	0	−0·16	−0·23	111	111	111	26			
5	−17·3	−140°	−280°	−1·63	+1·92	+0·03	+0·25	110	110	110	+27			
6	−28·4	−172°	−334°	−2·67	+2·48	+0·15	−0·11	102	102	102	−11			
7	−47·3	−226°	−92°	−4·45	+1·74	0	−2·76	36	113	14(*)	−39			
											+ 1			4,659

* By Simpson's Rule.

Immersed volume ... $v_1 = 1 \times 2\cdot 04 = 2$

Moment ... ... $M_1 = 4{,}659 \times 2\cdot 04 = 9{,}411$

$S_0\,\zeta_1 = 100$

$I\,\theta_1 = +\,64{,}878.$

TABLE XI.

Calculation of v_3 and M_3.

$$t = \frac{3}{4}\tau = 6^s{\cdot}75. \qquad \zeta_3 = 0{\cdot}26 + 0{\cdot}15 = 0{\cdot}41\,; \qquad \theta_3 = -5^\circ 24' = -0\ 0943.$$

$$z_1 = 0{\cdot}16 + 2{\cdot}5 \cos\left(\frac{2\,\pi\,x}{\lambda} - \frac{3\,\pi}{2}\right) - 0{\cdot}16 \cos\left(\frac{4\,\pi\,x}{\lambda} - \pi\right)$$

$$u = \zeta_3 + \theta_3\,x - z_1 = 0{\cdot}25 - 2{\cdot}5 \cos\left(\frac{2\,\pi\,x}{\lambda} - \frac{3\,\pi}{2}\right) + 0{\cdot}16 \cos\left(\frac{4\,\pi\,x}{\lambda} - \pi\right) - 0{\cdot}0943\,x.$$

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.
No. of the Cross-Section.	Abscissa x.	$\phi = \frac{2\,\pi\,x}{\lambda}$	$2\,\phi$.	$-\,0{\cdot}0943\,x$.	$-\,2{\cdot}5 \cos \phi$.	$+\,0{\cdot}16 \cos 2\,\phi$.	$u = 0{\cdot}25 + \text{V.} + \text{VI.} + \text{VII.}$	Ordinates of the L.W.L.	Ordinates at the Surface of Wave.	$\frac{\text{IX.} + \text{X.}}{2}$	Immersed Areas, $= \text{XI.}\,u$.	Immersed Areas, Stern Part.	XII. − XIII.	Moments XIV. x.
1	47·3	46° − π	92° − 2 π	−4·45	+1·74	0	−2·46	20	8	14	− 34	176	−210	− 9,933
2	28·4	− 8° − π		−2·67	+2·48	0·15	+0·21	82	82	82	+ 18	61	− 43	− 1,321
3	17·3	&c.	&c.	−1·63	+1·92	0·03	+0·57	102	102	102	+ 58	0	+ 58	+ 1,003
4	0			−0·0	0	−0·16	+0·09	111	111	111	+ 11			
5	−17·3	(See	(See	+1·63	−1·92	0·03	0	110	110	110	0			
6	−28·4	Table X.)	Table X.)	+2·67	−2·48	0·15	+0·59	102	102	102	+ 61			
7	−47·3			+4.45	−1·74	0	+2·97	36	82	59	+176			
											290			−10,251

Immersed volume ...	$v_3 =$	290 × 2·04	=	601.
Moment	$M_3 =$	− 10,251 × 2·04	=	− 20,912.
	$S_0\,\zeta_3 =$	1,149 × 0·41	=	471.
	$I_0\,\theta_3 =$	− 688,000 × 0·0943	=	− 64,878.

To obtain the values of α'_0, β'_0, α'_1, β'_1 (§ 9, Appendix), we have only to substitute the calculated values of v_0, M_0 . . . . v_3, M_3 in the formulæ (33) and (35). We get then—

$$\alpha'_0 = \frac{(S_0\,\zeta_0 - v_0) - (S_0\,\zeta_2 - v_2)}{2\,r} = \frac{(1{,}370 - 263) - (-874 - 434)}{5} = 483.$$

$$\beta'_0 = \frac{(S_0\,\zeta_1 - v_1) - (S_0\,\zeta_3 - v_3)}{2\,r} = \frac{(100 - 2) - (471 - 601)}{5} = 46.$$

$$\alpha'_1 = \frac{(I_0\,\theta_0 - M_0) - (I_0\,\theta_2 - M_2)}{2\,r} = \frac{(-4{,}406 + 15{,}280) - (4{,}406 - 3{,}700)}{5} = +\,2{,}033.$$

$$\beta'_1 = \frac{(I_0\,\theta_1 - M_1) - (I_0\,\theta_3 - M_3)}{2\,r} = \frac{(64{,}878 - 9{,}411) - (-64{,}878 + 20{,}912)}{5} = 19{,}886.$$

Thus—

$$\Delta\,a'_0 = \alpha'_0 - a'_0 = 483 - 475 = 8\,; \qquad \Delta\,b'_0 = \beta'_0 - b'_0 = 46 + 75 = 121.$$
$$\Delta\,a'_1 = \alpha'_1 - a'_1 = 2{,}033 - 774 = 1{,}259\,; \qquad \Delta\,b'_1 = \beta'_1 - b'_1 = 19{,}886 - 19{,}950 = -\,64.$$

On substituting these values in the equations (5) and (6) we obtain

$$\Delta\,\zeta = 0{\cdot}03 \cos\frac{2\,\pi\,t}{\tau} + 0{\cdot}33 \sin\frac{2\,\pi\,t}{\tau}$$
$$\Delta\,\theta = +\,0^\circ\,33' \cos\frac{2\,\pi\,t}{\tau}$$

The correction when made as above contains not only that part which results from "non-cylindricity," but also that resulting from the non-coincidence of the centre of gravity of the area of the ship's L.W.L. with the middle.

Calculation of the Bending Moment.

A sketch was given in § 3 of Part I. of the paper as to how to calculate the bending moment, taking the ship's motion into account. Here we give an illustration of the process of treating this subject, the wholly detailed treatment of which would require almost as much space as all the other parts of my paper, which would then be excessively long.

The bending moment being generally a maximum for a section close to the middle of the ship, and the variation of every function being slow near its maximum, we shall calculate the bending moment for the middle section of the ship under consideration.

If M_0 denotes the value of the bending moment at the middle of the ship on still water, we must add to it the moments resulting from the ship's inertia, and from the action of the waves. The first one is expressed by the following formula—

$$M_1 = -\,K_1 \frac{d^2\,\theta}{d\,t^2} - \frac{P_1}{g} \cdot l_1 \frac{d^2\,\zeta}{d\,t^2},$$

where K_1 and P_1 denote respectively the moment of inertia and the weight of the bow part of the ship, and l_1 the distance of its centre of gravity from the middle. The moment M_2 resulting from the action of the wave is—

$$M_2 = -\,S_2\,l_2\,\zeta - T_1\,\theta + r\,\varepsilon'_1 \cos\frac{2\,\pi\,t}{\tau} + r\,\gamma'_1 \sin\frac{2\,\pi\,t}{\tau},$$

where S_2 is the area of the bow part of the L.W.L., T_1 its moment of inertia, l_2 the distance of its

centre of gravity from the middle, and ϵ'_1 and γ'_1 quantities analogous to e'_1 and g'_1 (Appendix I., formulæ 22 and 23), but taken only for the bow part of the ship. We add also the moments—

$$- N\, l_2 \frac{d\,\zeta}{d\,t}, \text{ and } - N_1 \frac{d\,\theta}{d\,t}$$

of the resistance of water to the ship's oscillations.

Thus the complete expression of the bending moment is—

$$\begin{aligned} M &= M_0 + M_1 + M_2 \\ &= M_0 - K_1 \frac{d^2\,\theta}{d\,t^2} - \frac{P_1\, l_1}{g} \frac{d^2\,\zeta}{d\,t^2} - N\, l_2 \frac{d\,\zeta}{d\,t} - N_1 \frac{d\,\theta}{d\,t} - S_2\, l_2\, \zeta - T_1\, \theta + r\, \epsilon'_1 \cos \frac{2\,\pi\, t}{\tau} + r\, \gamma'_1 \sin \frac{2\,\pi\, t}{\tau} \end{aligned}$$

The constants being calculated quite in the same manner as above, we have—

$$\begin{array}{llll} K_1 = 148{,}000. & l_1 = 20^m. & N = 47. & M_0 = \frac{1}{60}\, P\, L = 9{,}000^{t.m}. \\ \frac{P_1}{g} = 250. & l_2 = 20^m. & \epsilon'_1 = +1{,}190. & S_2 = 575. \\ T_1 = 290{,}000. & N_1 = 41{,}000. & \gamma'_1 = +\ 8{,}800. & \end{array}$$

Then—

$$\theta = -\ 0{\cdot}006 \cos \frac{2\,\pi\, t}{9} + 0{\cdot}094 \sin \frac{2\,\pi\, t}{9}$$

$$\frac{d\,\theta}{d\,t} = \theta' = +\ 0{\cdot}004 \sin \frac{2\,\pi\, t}{9} + 0{\cdot}067 \cos \frac{2\,\pi\, t}{9}$$

$$\frac{d^2\,\theta}{d\,t^2} = \theta'' = +\ 0{\cdot}003 \cos \frac{2\,\pi\, t}{9} - 0{\cdot}047 \sin \frac{2\,\pi\, t}{9}$$

$$\zeta = 0{\cdot}26 + 1{\cdot}02 \cos \frac{2\,\pi\, t}{9} - 0{\cdot}15 \sin \frac{2\,\pi\, t}{9}$$

$$\frac{d\,\zeta}{d\,t} = \zeta' = -\ 0{\cdot}7 \sin \frac{2\,\pi\, t}{9} - 0{\cdot}1 \cos \frac{2\,\pi\, t}{9}$$

$$\frac{d^2\,\zeta}{d\,t^2} = \zeta'' = -\ 0{\cdot}5 \cos \frac{2\,\pi\, t}{9} + 0{\cdot}07 \sin \frac{2\,\pi\, t}{9}$$

On substituting, we have—

$$M = 6{,}400 - 4{,}363 \cos \frac{2\,\pi\, t}{\tau} + 2{,}625 \sin \frac{2\,\pi\, t}{\tau} = 6{,}400 + 5{,}092 \sin \left(\frac{2\,\pi\, t}{9} - 59^\circ \right).$$

Thus, the greater values of the positive and negative bending moments are—

$$M_{max.} = 6{,}400 + 5{,}092 = 11{,}492^{t.m} \text{ by } t = \frac{4}{10}\,\tau = 3{\cdot}6\, s.$$

The displacement P being nearly $5{,}000^t$ and the length of the ship 107^m, we have—

$$M_{max.} = \frac{1}{49}\, P\, L$$

These results are only given to illustrate the process of computation, and not as a general one.

DISCUSSION.

Professor J. H. Biles, Member of Council: My Lord and Gentlemen, I think this paper is an exceedingly valuable one. It is of great value, in the first place, as giving us a method of doing something we have been wanting to do for a considerable time, that is, to find out the best method of treating the stresses that come upon a ship when she is amongst waves. It is also a valuable paper because of the results that are deduced from this method. I think the title of the paper is not quite fair to the paper itself. It is called "A New Theory of the Pitching Motion of Ships on Waves and of the Stresses produced." Now, I think there is really nothing new in theory in the paper, and I think the paper would have been better called, "A New Method of determining the Pitching of Ships at Sea and the Stresses that come upon them." I merely make that remark because, I think, it will appeal more perhaps to those who cannot follow the mathematics of the paper, if it is understood to be a method of determining the pitching and stresses, instead of being a theory of the method. This subject is one which has been dealt with, from time to time, by some of our most eminent authorities. We had, beginning with Sir Edward Reed, the study of the disposition of weight and buoyancy in a statical condition, the poising of a ship on the crest of a wave, and the estimation of the bending moments. We had, following that, a very admirable investigation of the effect of the structure of the waves upon the bending moment, taking account of the wave pressures, *i.e.*, showing the modification in the pressures caused by taking account of the orbital motion of the particles. That paper was by Mr. W. E. Smith. Subsequently a paper was read here by our late lamented colleague, Mr. T. C. Read, upon the "Variation of Stresses on Ships in Waves," in which he took account of the vertical oscillation of the ship, and the effect upon the stresses of this vertical oscillation. That paper covers, to some extent, a good deal of the ground covered by Captain Kriloff. He covers it in an approximate way—a way analogous to the way Mr. Froude dealt with the rolling question, rather than the way in which Captain Kriloff has dealt with the pitching question to-day. The problem has been solved, I take it, by Captain Kriloff completely mathematically, without approximations that are other than approximations of mathematical processes; so that, I think we are a great step further ahead than we were in the last paper, because we have a complete solution. Mr. Read's paper, if I may so express it, gave the go-by to the pitching question by a very neat proposition, in which he showed that the inertia of the two ends of the ship tended to balance each other; that the loss of buoyancy at one end, when the ship was pitching, had to be compensated for by the excess of buoyancy at the other end, which left twice this excess available at one end of the ship to produce the pitching. That excess was available, one half for overcoming the inertia at the fore end of the ship, and the other half for the inertia at the after end of the ship. But, in the first place, we have a balanced moment representing the original bending moment of the ship when on an even keel—not dipping—less the unbalanced portion due to the want of buoyancy at one end. Those two Mr. Read expressed as $M - m$, the original bending moment, minus the bending moment taken off by the want of buoyancy. At the other end the moment was expressed by $M + m$, the original bending moment, plus the excess due to pitching down. Thus $M - m$ at one end was balanced by $M - m$ at the other, and you had these two little m's available for overcoming the inertia of the ship. To move the end where there was a defect of buoyancy, the moment necessary has to pass through the midship section, and in doing so it puts a bending moment of little m on that midship section, and added to the balanced bending moment already in it, $M - m$, makes a total $M - m + m$, which is M, the original bending moment, so that we have eliminated

the question of pitching. That was a very neat proposition, and I should like to hear Captain Kriloff take up that point, because I am not quite clear myself how the difficulty that comes in in the difference of results between the two can be quite explained. This paper is really such a comprehensive one that it is impossible to grasp every point of it in the short time that we have had. The method that Captain Kriloff lays down of determining the bending moment due to pitching, after he has determined the pitching angle and the position of the centre of gravity of the ship, which is on page 358, has given me some considerable amount of thought in trying to understand it clearly. He takes one end of the ship and deals with the moment of inertia of one end of the ship, and the weight of that end of the ship, and from that he determines the stress on the midship section. Now Mr. Froude is the recipient of paradoxes which he has to straighten out in some form or other. Perhaps he will be kind enough to help me out of this little difficulty. He has taken one for me to-day, and I will ask him if he will be good enough to do this one. Supposing you deal only with the moment of inertia of one end of the ship, you may leave the other end of the ship out of account altogether. You may change the disposition of weights in the other end of the ship, provided you do not alter the total weight and the position of the centre of gravity, and you may, therefore, vary the moment of inertia of the other end of the ship. Now, having seen that we may alter the moment of inertia of the after end of the ship without altering the stress, let us take the after end of the ship and calculate the bending moment from that, as Captain Kriloff has done; then, by similar reasoning, we may change the moment of inertia of the fore end of the ship, therefore we may change the moment of inertia at both ends of the ship, and the stress—the bending moment—will remain the same. I do not think that is quite correct; I think that is a paradox which will hardly fit in with this proposition that Captain Kriloff has worked out so well. There is, to my mind, a little want of clearness in this diagram (Fig. 2 Plate LVII.)—the diagram showing the bending moment—and perhaps I may state a difficulty which I got into, which Mr. Froude has helped me to get out of, in order to prevent others from falling into the same difficulty. The result deduced from this diagram by Captain Kriloff is that the bending moment, when the ship is not going ahead, is a maximum when the stern of the ship (as shown in Fig. 2) is highest, and is a minimum when the bow is highest. That is a point I could not understand, because it seemed to me that from the approximate symmetry of the two ends of the ship they ought to have been the same. But what has really to be taken account of, is that you start with a big positive bending moment in one direction due to being in still water, and that the bending moment is approximately the same in the two positions, only that it is reversed in sign. So that, if you consider the bending moment has a change due to waves, and set it off about the dotted line representing the bending moment which a ship would have in still water; then, when her stern is in the air, the bending moment due to the pitching is represented by the ordinate above the dotted line, and when the bow is in the air the bending moment due to the pitching is represented by the ordinate below the dotted line, and those two values are the same, only reversed in sign. So that what appeared to me, on the face of it, to have some error in it, on account of not fitting in with one's ideas of symmetry, is not an error, but due to the fact that our zero, in considering pitching, is the statical bending moment in still water, and not a zero of bending moment as shown by that line. I think it would be clearer to take that bottom strong line out altogether, and leave the dotted line as the real zero. Now, Mr. Read's paper took up the question of the additional stress, or change in the stress, due to vertical oscillations, leaving out of account altogether the pitching, for reasons which have been already stated, and I was interested to compare the results as they are stated by Captain Kriloff and the results obtained by Mr. Read. I cannot find in Mr. Read's paper the height of the waves stated, very probably it is there, and was one-twentieth of the length; but I

would like Captain Kriloff in the Transactions, if he be allowed to do so, to make a direct comparison of his results and the results obtained by Mr. Read. Captain Kriloff has shown that, with a bending moment of $\frac{1}{60}$th of the displacement multiplied by the length in still water, you get, by taking the pitching into account, a bending moment of $\frac{1}{49}$th; that is to say, there is an additional 22 per cent. of bending moment put on, on account of the pitching and vertical oscillation and action of the waves generally. Now, Mr. Read's results for dipping oscillation alone showed that the sagging moment was increased by this dipping oscillation 21 per cent. from a bending moment of $\frac{1}{50}$th of the displacement multiplied by the length with which he started. That is apparently a very close confirmation, but I am not quite sure that the bases of the work are the same; and I think it would be very useful if Captain Kriloff would make the connection between those two papers complete by stating the actual results of his work in relation to Mr. Read's. There is a point I mentioned in a paper which I read, not at this Institution, but at another Institution, which is of some importance in this connection, and that is, the effect of the ship upon the orbital motion of the water when she is going head to sea, as against when she is going with the sea. There must be a very considerable upset of the orbital motions, and that upset can only take effect in an increase of pressure. I should like Captain Kriloff, if he will, in his reply, to say how much, in his opinion, he thinks that the upsetting of the orbital motions in the vicinity of the ship modifies the supporting forces on the ship. There is one point of practical importance which I should like to point out. In calculating, as we do now, the bending moment of a ship on the crest of a wave, taking account of the wave pressures, the method that is now adopted is to construct a curve representing these pressures in each cross section, and to find the area of the curve, and so find the supporting force throughout the length of the ship. When you have found that, you have found, not what you want, but something different, and you have to begin again, and, by a process of trial and error, to arrive at the exact position of the ship on the wave. This simple method of Captain Kriloff will enable us to write down at once the exact position of a ship on a wave, *i.e.*, we should be able to write down at once the ordinates of this wave on the ship's side, and arrive at the exact position of the ship on the wave, and determine the exact bending moment of the ship; and, even if we do not go into the question of the pitching, and merely deal with the ship, neglecting the pitching, this method is shorter and simpler than the one we have been obliged to adopt hitherto.

Mr. R. E. Froude, F.R.S. (Associate Member of Council): My Lord, this paper contains so much matter that I will endeavour to confine my remarks to a few of the points that have been dealt with. Perhaps I had better first touch upon the point as to which Professor Biles appealed to me, although I think I had better leave Captain Kriloff to answer Professor Biles in the main. I will say this much, that I think Professor Biles is omitting to take account of the fact that the angular acceleration which the ship is undergoing, which, taken together with the moment of inertia, is the measure of the stress she will undergo, has already been once taken account of—that angular acceleration has already been determined, taking the moment of inertia into account; so that you cannot after that go and alter the moment of inertia and say the bending moment will remain the same. I think that is the clue to Professor Biles' difficulty. The paper seems to me one of the most interesting and valuable papers we have had for a very long time. It describes a most elaborate and intricate investigation, carried out in a thorough and perfectly sound way, and in an admirably systematic and workman-like manner. From an academic point of view its value seems to me beyond praise. In saying that I do not wish to imply that its practical value is in any way small; but I mean that it is the experience of anybody who undertakes an elaborate theoretical investigation of this

difficult character, that perhaps nine-tenths of the work one has to do consists in studying the effect of certain complications, and finding out that they need not be taken into account at all. And so in this case, as Captain Kriloff said, the mathematics, of which the greater part of this paper consists, are occupied in showing that the complications introduced by the non-sinusoidal character of a wave, and the variation in hydrostatic tension, and the departure of the ship from a truly vertical cylindrical form, need not be taken into account. It does not follow, however, although those complications may be neglected as a general rule, that circumstances may not arise where the method of investigation of them which Captain Kriloff has adopted will not become serviceable. But taking Captain Kriloff's statement that, for general purposes it is not necessary to take those complications into account, we are left with the two equations on page 333, Nos. 11 and 12. These show that the whole motion of the ship, which is to be taken into account, consists of two simple independent oscillations. I call them independent, because, although they are taking place simultaneously, their action is independent, and may be considered independently. Those two oscillations are the bodily dipping oscillation of the ship and the pitching oscillation. The first equation refers to the dipping oscillation and the second to the pitching. Those two equations, by a certain transmutation of symbols, which I have written out and handed to Captain Kriloff,* may be converted into a form which is identical with the ordinary differential equation for rolling when resistance is introduced, of which I gave a paraphrase in my own paper. The equations, then, amount in effect to the representation of the effective wave-slope for pitching and the effective wave-height for dipping by the actual slope and height with qualifying co-efficients. Now that is, of course, a thing that has been done before, but only, as far as I know, as it were, *ad hoc*, and in particular cases. It has never, I believe, been formulated in that perfectly systematic way in which Captain Kriloff has formulated

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* The paper referred to is as follows :—

In the right-hand side of equation (11), page 333, the quantity which stands as—

$$= r\left(a'_0 \operatorname{Cos} \frac{2\pi t}{\tau} + b'_0 \operatorname{Sin} \frac{2\pi t}{\tau}\right)$$

may be written

$$= S_0\, c_0\, h\,; \qquad (11\ a)$$

where h is the momentary elevation of the wave surface above mean level at a distance l_0 from the midship; c_0, l_0 being constants dependent on the form of ship and ratio of her length to the wave length, just as a'_0 b'_0 are; and similarly determinable.

On similar principles, the quantity in the right-hand side of equation (12), which stands—

$$= q\, r\left(a'_1 \operatorname{Cos} \frac{2\pi t}{\tau} + b'_1 \operatorname{Sin} \frac{2\pi t}{\tau}\right)$$

may be written

$$= P\,(R - a)\, c_1\, \theta', \qquad (12\ a)$$

where θ' is the momentary wave-slope at a distance $= l_1$ from the midship.

The equations are then identical with the ordinary differential equation for rolling, with resistance introduced, of which I give a paraphrase in my own paper just read (equation 12, § 21), the terms $(S - c_0\, h)$ and $(\theta - c_1\, \theta')$, respectively, corresponding to the usual $(\theta - \theta')$.

The purpose of the determination of the constants a'_0, b'_0, for equation 11; and a'_1, b'_1, for equation 12, is thus seen to be equivalent to determining, respectively, the relation between the mean effective wave-height and its actual extreme height for dipping oscillation; and the relation between the mean effective wave-slope and the actual extreme wave-slope for pitching.

it. From those differential equations, of course, you get a resulting oscillation of precisely the same character as the rolling oscillation which I explained in my own paper. You have forced oscillation and super-imposed free oscillation extinguished by resistance, resulting in a non-uniform oscillation which quickly becomes uniform. As to the oscillations which will result, Captain Kriloff says in his paper that for all cases, except synchronism, or approximate synchronism, the resistance co-efficient is practically unimportant. That is a result that appears from my own investigation on rolling, if you take only the "ultimate uniform oscillation"—namely, the oscillation which would be permanent and continuous if the sea was perfectly uniform. As regards that uniform oscillation, we have seen that difference in the resistance produces scarcely any difference in the rolling when the departure from synchronism is moderate. But we have also seen that the maximum of the precedent non-uniform oscillation may be affected very considerably by the resistance; and, seeing that in our experience pitching seems, on the whole, quite as non-uniform as rolling, I think it is quite possible that resistance may, for that reason, have more importance than Captain Kriloff has attributed to it.

Mr. Archibald Denny (Member of Council): My Lord, Professor Biles has referred to work done by Mr. T. C. Read, whom we all regret is no longer with us. I am delighted with the work that Captain Kriloff is doing. I am always on the look-out, as a more or less practical shipbuilder, to get out of this mass of scientific figures some practical results to enable us, if possible, to determine more accurately the stresses we get on actual ships; and I would like very much if Captain Kriloff would go further into the matter which Mr. Read began, and let us have some solution as to the difference in stress in full and fine ships, when in a seaway. I know that in his paper there are the materials for it; but I would be very glad if Captain Kriloff would solve that problem for me. I admire Captain Kriloff's pluck in mathematics. Even now he is not satisfied with what he has done, but he tells us he is going to do a great deal more. I am sure the Institution will be delighted when Captain Kriloff submits the result of his investigations, and I personally thank him very much for his paper.

Professor A. G. Greenhill, F.R.S. (Visitor): My Lord, may I be allowed to make a suggestion for the consideration of the author of this paper. I think it would add to the interest of these beautiful diagrams if the author would add views, alongside, of the same ship rolling in the sea, showing the rolling motion at the same time as the pitching motion. It is not a matter of practical interest to know how a ship would roll when going broadside through the water at 12 knots, so that these additional figures need only be inserted on the first sheet of the diagram; but, by a combination of the rolling motion exhibited in those figures with the pitching motion already shown, it would be possible to construct, for all practical purposes, the motion of a ship steaming at an angle with the waves, not necessarily steaming head to the sea, as shown here in these diagrams.

Sir Edward Reed, K.C.B., F.R.S. (Vice-President): My Lord, I should just like to say how much we are indebted to Captain Kriloff for this paper. I am sure everyone who has been connected with this Institution, from the first, will feel that he has made to it a most valuable contribution in that branch of science which is most difficult to pursue with success. I should have said a word or two about his remarks on my paper, which are perfectly true and perfectly just; but Professor Biles has given such an admirable summary of the science of this subject, as we know it, in the opening part of his remarks, that he has made any observations of mine unnecessary. Therefore, I only rise as an old member of the Institution to express our grateful thanks to Captain Kriloff, and our admiration of his work.

Captain KRILOFF (Associate): My Lord and Gentlemen, I shall give my replies in the inverse order of the remarks. In the first instance, I beg Sir Edward Reed to accept the expression of my most grateful thanks for his kind expressions, and for the honour he did me by his remarks.

Professor Greenhill suggested he would like to see end views of the ship represented on these diagrams. I would be very glad indeed to give an immediate answer to this suggestion; to prove that I have thought thereupon I shall read what I say in § 7 at the end of my paper, "we have only considered the ideal case of pure pitching, the ship steaming at right angles to the crests of waves. If this angle is an oblique one the pitching is accompanied by rolling, and the problem becomes of a still more complex character, though the method of solution given in the Appendix is also applicable to it, as we shall show in another paper." In § 12, at the end of the Appendix, I say, in two words, in what the difficulty consists. There it is stated:—"If the ship's head is oblique in relation to the crests of waves, there is rolling combined with pitching; the angle of rolling being often a large one, the strictly mathematical treatment of the problem requires the use of elliptic functions;" because, as you see, Professor, we must start from the Eulerian equations of the motion of a solid body, "and I am afraid there is already too much mathematics in my paper to introduce into it elliptic functions, that bugbear for practical men. I shall put it off to another time, when I shall again have the honour to submit to the Institution of Naval Architects the theory of rolling and pitching combined, properly illustrated by numerical examples and diagrams, which, perhaps, will reconcile even practical men to a small dose of elliptic functions, this greatest mathematical gain of our century." To sweeten this dose I have only to take it from Professor Greenhill's luminous treatise on elliptic functions.

I shall do all I can to answer, in a paper of a quite practical character, all the questions which Mr. A. Denny suggests. In this one my intention was only to briefly sketch a method more rigorous than others for the calculation of stresses, the principal subject of the paper being the treatment of the pitching motion.

Mr. Froude, who maintains so highly and successfully an unrivalled inherited authority in all the principal branches of theoretical naval science, made remarks which are so favourable to my paper, that, on expressing to him my thanks for his kindness, I shall only add that the form $c_0 h$ and $c_1 \theta'$ which he suggests are so general, so long as the co-efficients c and c remain undetermined, that they can serve to express everything you like. I show in my paper how to calculate the *numerical* values of constants equivalent to these c_0 and c_1, in order that these general expressions may represent the motion of a *given* ship on *given* waves. The waves ought by no means to be "trochoidal," they may even be "pyramidal," as mentioned by Sir William White; but, to calculate the pitching or rolling they produce, these waves must be *given;* that is, we must have three, or even four (in the most general case) equations, like equations 1, 2, and 3 of the Appendix, expressing the position of every particle of water at every moment of time, and the pressure at every point for this moment. The final expressions for the motion of the ship will change their form, but the method developed in the Appendix remains unaltered.

Professor Biles directed his chief attention to that part of my paper which is only briefly sketched and, therefore, naturally incomplete, and sometimes rather obscure, *i.e.*, to the calculation of stresses. This I shall explain further. As to the title of my paper, it seems that I have used the word "theory" in a sense which is not a common one. On using this word I wished to attribute to it the sense it has in astronomy. When we say "the theory of the sun," or "the theory of Venus," or "the theory of the moon," we understand that the subject is to explain and to give a method of

determining, at every moment, the place occupied by the respective heavenly bodies. Thus the theory of pitching is a method of determining the positions taken by a pitching ship on waves. If the sense stated be attributed to the word "theory," my title is equivalent to that proposed by Professor Biles; but I must quite agree with Professor Biles that the title he proposes is much better and more convenient than mine, because it makes impossible any misunderstanding.

It would be too long a matter to give all the restrictions under which the statement quoted, of the late Mr. T. C. Read, that inertia of pitching and moments of trim need not be taken into account as balancing each other, is true, because it is very far from being an absolutely true one. For the moment I prefer to explain my method of proceeding, and I shall prove that the bending moment, proceeding from *inertia* of the pitching motion at the midship section* is expressed by the product of the angular acceleration by the moment of inertia of that part of the ship (say the bow) for which all the other moments (weight, buoyancy, &c.) are taken, this being the principal point which seems paradoxical to Professor Biles.

Let us remember how the bending moments acting on a beam are generally to be calculated; if A B C is a beam, supported at B and loaded at the ends A and C, like this stick in my hand, then, to calculate the stress at the section D, between the support B and the end A, we have to take the moments of all the forces acting on segment, say A D, in respect to the section D. We could take the moments of all the forces acting on the other segment C B D, taking, of course, the reaction of the support at B into account; we should obtain precisely the same value for the moment, but of a reversed sign, the sum of the two moments for both ends being always zero, as the beam as a whole is in equilibrium. Now, applying to our beam the same reasoning as Professor Biles has just applied to the ship, we come to the paradoxical result that the loads of a beam can be changed *ad libitum* without any change of stress. From the manner in which I bend this stick you can see if the result is true. Why, then, is the above result not true? Because when we say, as the moment at D is obtained from the loads acting on the segment A D, thus we can change the loads on the segment C B D *ad libitum*, without altering the bending moment at D. This we cannot do, because the beam must remain in equilibrium after the change of loads, as it was before; therefore, if I change the loads on the segment C B D, I must also change the force at A, just as for this stick, when I change the pressure of my hand at C, the pressure at A changes by the same amount, and therefore the bending moment alters for every section. In the case of the ship, if you change the distribution of loads for the stern part, the moment of inertia of the ship will change, the acceleration will be changed, and therefore the forces of inertia, not only of the stern part, but of the bow part also, will be changed, quite as naturally and, so to say, automatically as in the case of this stick. This Mr. Froude has very well expressed in two words.

To calculate the bending moment for any section of a ship, quite the same process is to be applied as for the beam. Thus, if B S is a ship on a wave, to calculate the bending moment at any section, say, the middle, M, we have to take the moments of *all* the forces acting on the bow part B M, or on the stern part S M, the result as to the value of the moment will be precisely the same. Let us take, for example, the bow part. The forces acting are the following: (1) the weight of all the loads; (2) the buoyancy; these two only so long as the ship is at rest and has no vertical oscillations. If the ship is in motion we must add (3) the vertical component of the forces of inertia, this being measured

* For other sections yet another term is to be added.

by the product of the mass of the particle considered by the vertical component of its linear acceleration, and directed contrary to the acceleration.

The calculation of the bending moment will be much simplified, if, at first, we calculate the bending moment on still water and for the upright position of the ship; it remains then only to add to this moment, the moment of excess or defect of buoyancy for the part contained between the ship's load-line and the surface of the wave, this represents the principal part of the action of wave and of the trim. As there was no question about the expression of these moments in my paper, I have only to explain the expression for the bending moment proceeding from the forces of inertia. On calculating the moment of weights, we have considered the *true* weight of every load, but when in a state of non-uniform motion it is the *apparent* weight which is in action, the difference between the two being the force of inertia. Let m be a particle of the mass m at a distance r from the middle plane; then, if ω' is the angular acceleration, the vertical component of the linear acceleration of m is $\omega' r$ and the vertical component of the force of inertia is $- m \omega' r$; the moment of this force respectively to the middle is $- m \omega' r . r = - m \omega' r^2$. To obtain the resultant moment we have to take the sum of all these partial moments for all the particles situated at one side of the midship section—the bow side in our case—this gives bending moment of the forces of inertia $= - \Sigma m \omega' r^2$, the factor ω' being common to all terms; the above sum $= - \omega' \Sigma m r^2$; it is the product of the angular acceleration by the moment of inertia of the end of the ship considered—the *bow* end in our case. Q.E.D.

If we had performed our calculations beginning from the stern, we should have obtained quite an analogous result, but always we should have to deal with the moment of inertia of one end of the ship. I believed this consideration was so simple, and derived so naturally from the first principles of the calculation of moments, as to require no explanation, especially in the mathematical part of the paper, the problem being in such a close connection with the classical one of the stresses of a pendulum bar. Professor Biles asked me also as to the amount of the change of pressure from the upsetting of the orbital motions of the particles of water close to the ship. I believe nobody in the world could give an exact value for this, because it would require the integration of the Kirchhoff equations of motion of a solid body in a fluid, and of the fluid surrounding it. This implies difficulties, that have been surmounted only in the simplest cases. Perhaps the analysis of the chrono-photograph of a pitching ship in a seaway, of which M. Bertin has told me, will help to obtain a practical solution of this difficulty as of that of the true amount of the resistance of water.

In finishing my reply, I feel it my duty to present my most grateful thanks to the Institution of Naval Architects, and especially to its Council, for the honour of being allowed to read a paper before such a distinguished body, and of being admitted an Associate of this celebrated Institution.

Note added.—Professor Biles wished to have a comparison of my result with those of the late Mr. T. C. Read. The moments being calculated as shown in my paper and explained above, let us see when there will be a compensation between the trimming moment and the moments of the forces of inertia of the pitching produced. We shall consider only bending moments at the midship section. Let us denote by M_B and M_S the trimming moments resulting respectively from the bow and the stern parts of the ship, and by K the total moment of inertia about the transverse axis passing through the centre of gravity. Then, if resistance of water be neglected, we shall have the following equation of the pitching motion of the ship—

$$K \omega' = M_B + M_S \text{; or } M_B + M_S - K \omega' = 0 \qquad (1)$$

where ω' is the angular acceleration.

Now, as was explained, the part to be added to the bending moment on still water is $M_B - T_B \omega'$ where $T_B = \Sigma m r^2$, the sum being taken for all the loads of the bow part, *i.e.*, the moment of inertia of this part relatively to the plane of the middle section. The quantity $M_B - T_B \omega'$ will be zero, according to equation (1), if $M_B = M_S$, and if $T_B = \frac{1}{2} K$; that is, if the forms of the bow and stern are symmetrical, and if the moment of inertia of the bow part is equal to the half of the total moment of inertia. These are precisely the conditions stated by Mr. T. Read when he obtains the proposition that inertia of the pitching motion and the trimming moments balance each other.

This condition is satisfied for the midship section of the greater number of ships; only for several ships of war, with unsymmetrically distributed turrets, there is a considerable difference of the two moments of inertia. But if we take the bending moments for sections other than the middle, Mr. Read's statement is no more applicable, and we must recur to the general method of taking the sum of the moments of all the forces acting on one end of the ship which remains unaltered, and gives immediately the required algebraical expression of the moment of the forces of inertia and others. It is useful to form such algebraical expressions in order to properly arrange the numerical calculations, which become extremely simple in the case considered, and easily performable graphically, as I shall show in the paper which I promised in my reply to Mr. A. Denny.

The President (the Right Hon. the Earl of Hopetoun, G.C.M.G.): Gentlemen, I think we owe a deep debt of gratitude to Captain Kriloff for the paper that he has read, and I think, too, we may offer him our sincere congratulations on the knowledge which he has attained of our language. It is no light thing for a man to deal with highly technical matters in a language which is not his own. I am certain his contribution will prove an extremely useful one to the Institution and to science generally, and I am sure the Institution also deeply appreciates the trouble he has taken in making the journey, which he has made, to read this paper to us.

NOTES ON THE CARRIAGE OF GRAIN CARGOES.

By Geo. Herbert Little, Master Mariner, late Student Royal Naval College.

[Read at the Thirty-seventh Session of the Institution of Naval Architects, March 27, 1896; Sir Edward J. Reed, K.C.B., F.R.S., Vice-President, in the Chair.]

It is with some diffidence that I submit this paper to the members of this Institution, inasmuch as it propounds no new thesis in naval architecture, neither does it discuss the subject-matter with that degree of authoritative knowledge and experience which is desirable in order to give it some value as a contribution to the technical literature of the profession. The carriage of grain cargoes has engaged the attention of many distinguished members of this Institution, and I do not presume to think that I can supplement in any way the researches of Professors Elgar, Jenkins, and Greenhill. It did, however, seem to me that their investigations were not so well known to, or appreciated by, those engaged in the carriage of grain as could be wished; indeed, even those whose duty it is to investigate maritime losses show that, their acquaintance with the higher professional literature is of the slightest; hence some attempt to apply practically the teachings of these eminent naval architects may possibly be of service.

It is a matter of common knowledge that the carriage of bulk cargoes is attended with considerable risk, arising from the liability to shifting, which ensues as a consequence either of depreciation in the volume of the cargo or of bad stowage, or of both. The annual loss of property from this cause is very large, but difficult to estimate with accuracy, as the published statistics do not recognise shifting cargo as a specific cause of loss.

As regards steamers it will generally be found that those returned as foundered and missing carried bulk cargoes; and we are justified in attributing many of these losses to shifting. As regards sailing ships, these vessels are particularly susceptible to two causes of loss, both of which are largely, if not wholly preventible, and which can and ought to be eliminated. They are, fire (included under "other causes") and cargo shifting. So serious have been, and are, the losses of sailing ships, that the rates of marine insurance have during the last few years been doubled, and in some instances

nearly trebled. A well-known underwriter not long ago said that, speaking roughly, one-half of this increase is for losses by fire, and the other for losses arising from cargo or ballast shifting. When we consider the general design of the modern sailing ship, the total absence of subdivision, the deficient pumping power, the large stability when coal-laden or when in ballast, it is not surprising that losses from these causes are so frequent. Dismasting is another danger to which sailing ships are very liable, and one which is also largely preventible. In short, both in design and management, the sailing ship of to-day is a negation of many of the more important principles of safety.

Grain cargoes are carried in British vessels according to regulations made under the Grain Carriage Act of 1880. One of the most important, and at the same time most ignored provisions of the Act, says: "All necessary and reasonable precautions, whether prescribed by this Act or not, shall be taken in order to prevent the grain cargo from shifting." Practically, this means a perfunctory compliance with the Act in the matter of feeders, and a careful discrimination in the matter of their capacity. The more important details, such as efficient subdivision, means for dealing with a shift of cargo, and the vital questions of ballast and stability, are not regarded as "necessary and reasonable precautions." By Section 5, the Act does not apply to regulations made by the Board of Trade. As a consequence of this, some of the principal underwriting associations have drawn up rules for grain cargoes, more or less satisfactory; while the Board of Trade has at various times placed its interpretation of the Act, and its ideas on grain cargoes in general, before the shipping public, in the shape of certain Delphic utterances known as "Official Notices." These, however, like the underwriters' regulations, wholly ignore the question of stability. In all these regulations, official and otherwise, great importance is attached to feeders and their capacity; the idea being, that a head of grain in a feeder is analogous to a hydraulic head, and that the grain in it, in virtue of its potential energy, will raise the level of the grain in the hold. In point of fact, the idea is fallacious; I have observed what I term "wedges of vacancy" quite abreast of the feeders. Feeders are, however, useful as reservoirs of grain to make good by manual transportation any loss caused by shifting.

Shipowners have found it convenient to avail themselves of the power vested in the Board of Trade under Section 5, and have obtained the approval of that authority for various "plans of loading." We then have this extraordinary and anomalous result, that a vessel intended to carry grain may load under three separate conditions: she may be loaded in accordance with the Act itself; she may be loaded in accordance with regulations approved of by the Board of Trade; or she may be loaded in accordance with a plan of loading sanctioned by the same authority. The effect of this is that, if a vessel is furnished with a Board of Trade "plan of loading," she may stow part of the

cargo under the Act, and part under the plan; in both cases there is not necessarily any infraction of the law, although the vessel may be lost as a consequence of the cargo shifting. By having an official plan of loading, and by complying with Official Notice 6, a vessel becomes what is known as "doubly exempt," that is, she is privileged to load under either dispensation without incurring any obligations attaching to the plan. In other words, such a vessel, by exhibiting outward and visible signs of compliance with the law in the shape of feeders, &c., may nevertheless be improperly and dangerously laden. The object of the Act and of any plan of loading is the same, *i.e.*, safe stowage. Official plans of loading are not necessarily on all fours with the Act, indeed are seldom so, but if good stowage is assured by the Act, why dally with a "plan"? And if salvation is only found in a "plan," of what use is the Act? Again, in getting out a plan of loading the question of stability cannot be ignored, or rather, any plan of loading which is not based upon accurate data of the vessel's stability is positively misleading; and yet we see the Board of Trade issuing, with a light heart, "plans of loading," "official notices," and "instructions" about loading the most dangerous, nearly, of all cargoes, without possessing any reliable data of the stability of the vessels they are dealing with. It is true that the plans of loading for steamers approved of by the Board of Trade are issued subject to the conditions that as laden the vessel shall have "sufficient stability"; but what is the definition of sufficient stability? Inasmuch as these plans do not provide stability after a shift of cargo, it seems that there is no advantage so far as safety is concerned in following them. What is wanted in a plan of loading for a grain cargo is, the assurance that, either the possibility of shifting is entirely precluded, or, that there will be sufficient stability *after* a shift of cargo; and no measures of a legislative nature, which do not fulfil either of these conditions, can be deemed satisfactory.

The two essential conditions for a shift of cargo are, vacant space in which to shift, and the operation of some external force by which relative motion is imparted to the ship and cargo. The former is largely a matter of stowage and trimming, and when there is time and opportunity to make good stowage, very little shifting will occur. Unfortunately commercial exigencies too frequently prevent good stowage, as the cargo is loaded so rapidly. The influence of space is determined by the efficiency of the longitudinal subdivision adopted; and the more perfect and extensive this is, the less is the necessity for careful trimming.

If, when loading grain in bulk, we could ensure that all the space would be filled, shifting would, of course, be impossible. In vessels of certain types this end is attained, but in vessels of ordinary types vacant spaces of greater or less extent are practically unavoidable. After the grain is shipped some amount of settlement occurs even in the most carefully stowed vessels, and hence there will be some space between the surface

of the grain and the underside of deck, and this notwithstanding the proximity of feeders. These latter, indeed, cannot be depended upon to do more than feed a very limited area in their vicinity. In fairly well stowed steamers the bulk grain, at the end of the voyage, will have a surface from six to twelve inches below the underside of deck, and even in cases where the trimming, &c., has been most carefully done the grain surface will be seldom higher than the bulb of the beams. On the other hand, where, from various causes, the trimming has been indifferent, large depressions will exist in the grain surface. The amount by which bulk grain will settle has been estimated at from 5 to 8 per cent. of the depth of the hold; this would correspond to a space of nine inches in depth in a hold fifteen feet deep.

The most important fitting required for vessels carrying coal, grain, or other homogeneous cargoes in bulk, is undoubtedly the longitudinal middle line bulkhead, or, as seamen say, the shifting boards. I need not tell members of this Institution the purpose for which this is fitted, but if we may judge from the evidence given at the inquiries into the losses of grain-laden steamers, it will be gathered that seamen hardly appreciate this fitting at its proper value. Indeed, from the commercial point of view, subdivision is generally regarded with extreme disfavour. It may, however, be stated as a canon of seaworthiness for all vessels carrying bulk cargoes, that a longitudinal mid bulkhead is essential.

Preferably, it should form an integral part of the structure of the vessel, as its present temporary character leads to improper construction. Especially is this the case just under the beams. I would here suggest whether a diaphragm plate could not be worked between the beams, and of the same depth. The great value of an efficient longitudinal bulkhead in preventing shifting of mobile cargo such as grain, and in preventing any serious diminution of the stability, has formed the subject of a most able investigation at the hands of the late Professor Jenkins.* Briefly, the learned Professor shows that if in a vessel having no mid line bulkhead and a free cargo surface, a shift of w tons through a distance of d feet produces an inclination of a°; by fitting a mid line bulkhead, the weight of cargo that can now shift is $\frac{W}{2}$, and the angle of inclination is but $\frac{a^\circ}{4}$. This shows the great importance of making the bulkhead absolutely grain-tight; and too much pains cannot be taken to ensure this end. Professor Jenkins' investigation had, however, special reference to liquid cargoes, and for grain some modification is necessary.

It is well known that grain-laden steamers have generally but very small stability, and that this stability is liable to be wholly absorbed by a comparatively small shift of

* "On the Stability, &c., of Oil Carrying Steamers." *Vide* "Transactions of Engineers and Shipbuilders in Scotland," Volume xxxii. page 225.

cargo. It would then seem to be but prudent to ascertain before sailing the stability under the given conditions of lading, and how this will be affected by the shift of any stated quantity of cargo. There should be no difficulty in estimating rather closely the greatest quantity that *can* shift, and hence a margin of stability could be ensured. When shifting occurs in a grain-laden steamer the common C. G. of ship and cargo moves from its normal position in the longitudinal mid plane, in a direction parallel to the line joining the C. G. of the shifting mass before, and after shifting. The vessel then inclines to some angle at which the C. B. and C. G. are in the same vertical line, when equilibrium is re-established.

Consider the case of a grain-laden vessel having no longitudinal mid bulkhead, or what is the same thing, leaky shifting boards. In Fig. 1, Plate LVIII., D K is the under-side of the deck, and S F the free surface of the cargo. Suppose shifting has taken place, the cargo surface will now be S′ F′, and it is evident that the "Wedge of Vacancy" S K′ S′ = the space occupied by the shifted cargo F′ K, F K′. In order to equate these, let y be the half beam, and express the original depth of the vacant space, h, in terms of y thus : $\frac{y}{n} = h$; let θ be the angle of repose of the grain, and let D F′ = x, and S K′ = d, let also l be the length of the free surface. (The length of free surface in ordinary cargo steamers, excluding that in wake of hatchways, may be taken at 40 to 50 per cent. of the length of the vessel.) Then it can be shown that if w be the number of cubic feet per ton of grain, that the weight of the shifted cargo W will be—

$$W = \frac{d^2\, l \tan\theta}{2\, w}$$

the distance—

$$g\, g' = \frac{d + 6\, y}{6}$$

and—

$$G\, G' = \frac{d^2\, l \tan\theta}{2\, w\, D} \cdot \frac{d + 6\, y}{6}.$$

and the angle of heel produced will be—

$$\mathrm{Tan}^{-1}\, a = \frac{d^2\, l \tan\theta}{2\, w\, D . G\, M} \cdot \frac{d + 6\, y}{6}.$$

If there be a grain-tight longitudinal bulkhead, the weight of cargo that can shift, and its moment, will only be $\frac{1}{4}$ of that given above. It is then a simple matter to say whether a shift of a stated quantity of cargo will absorb the stability to a serious extent.

In order to illustrate the importance of having grain-tight filling pieces between the beams, consider the case of a steamer 40 ft. beam, and having a free grain surface 1 ft. below the under side of deck; and suppose one filling piece has become displaced; we have—

$$y = 20 \text{ ft.},\ l = 2 \text{ ft.},\ n = 20,\ d = 7{\cdot}7 \text{ ft.},\ \theta = 30^\circ, \text{ and } w = 40\,;$$

then the weight of the cargo that can shift will be—

$$\frac{7{\cdot}7^2 \times 2 \times {\cdot}58}{2 \times 40} = {\cdot}76 \text{ ton,}$$

and the moment produced will be—

$${\cdot}76 \times \frac{7{\cdot}7 + (6 \times 20)}{6} = 14{\cdot}96 \text{ foot tons.}$$

In a classical paper read before this Institution, "On the Shifting of Cargoes," Professor Jenkins shows how rolling influences shifting, and how the angle of inclination at which shifting occurs is determined by the angle of repose of the grain and the G.M. This investigation has been continued by Professor Greenhill in his admirable paper read before this Institution, on "The Stresses on a Ship due to Rolling." In this paper we are shown how to measure the magnitude and direction of the forces acting upon the cargo at any angle. With these three papers, and that one by Professor Elgar, also read before this Institution, the phenomena of cargo shifting become beautiful examples of the action of physical laws. I may be permitted to remark, that I look forward to the time when these papers will form part of the curriculum of every shipmaster, or at least of every Board of Trade Assessor and Inspector, as until one has mastered them, it is not easy to appreciate the forces producing shifting.

In order to see how stability influences the tendency to shift, it is interesting to compare two vessels of the same type, and of the same displacement approximately, but differing in their relative proportions. Steamer A is 320 ft., by 39·5 ft., by 28·75 ft. D = 5,900 tons; $\frac{D}{B} = {\cdot}73$. When laden with a grain cargo the G.M. is ·67 ft. The curve of stability is shown on Fig. 2, Plate LVIII. From this it will be seen that the angle of maximum stability is at 38° when G Z = ·325 ft., and the stability vanishes at 58°. Her radius of gyration is assumed to be 13 ft., and her period (single roll) is 8·5 sec.

Steamer B is 320 ft., by 44 ft., by 23·5 ft.; D = 5,730 tons; and $\frac{D}{B} = {\cdot}53$ ft. When laden with a grain cargo her G.M. is 1·5 ft. The curve of stability is shown on Fig. 3, Plate LVIII. From this it will be seen that the angle of maximum stability is at 58° when G Z = 1·17 ft., and the stability vanishes at 89°. The radius of gyration is 14 ft., and her period is 6·5 sec. Both vessels have water ballast. Shifting will commence in both vessels when, during rolling, they reach an angle of inclination nearly equal to the angle of repose of their cargo; but at a rather smaller angle in the case of steamer B, showing that, under the conditions stated, shifting is a little more likely to occur in the beamy, shallow, and stable vessel than in the narrow, deep, and comparatively unstable one.

In Figs. 4 and 5, Plate LVIII., I have applied Professor Greenhill's investigation to

these two vessels under two different angles of inclination, the full lines representing the direction of the various forces for an inclination of 20°, and the ticked lines the forces for an inclination of 10°. The vessels are supposed to be rolling through an arc of 50°.

The moment of inertia of each vessel is given by D K^2, and each oscillates like a pendulum of length G L, given by—

$$G\,L = \frac{K^2}{G\,M}.$$

In the case of steamer A, G L = 254 ft., and in steamer B, G L = 130 ft. The actual vessel in the diagram is represented by the small outline round G; the larger outline being drawn for clearness. In other respects the diagrams are drawn in accordance with Professor Greenhill's paper.

This investigation also enables us to apply the pendulum to indicate when shifting will occur. The first movement of grain in bulk is often so insidious as to escape attention, and a considerable shift may take place, especially in a seaway, without it being known. If, however, we suspend a pendulum at P, shifting will occur whenever the angle between the direction of the pendulum and the normal to the grain surface exceeds the angle of repose. The resultant of gravity and the total reversed effective force at P is determined by the ratio $\frac{I\,R}{G\,I}$, and this resultant acts in a direction parallel to I R. On referring to the diagrams, it will be seen that, for similar angles of inclination, this resultant in steamer B is much more transverse in direction than in steamer A, indicating a greater tendency to shifting in the broad stable ship than in the narrow and comparatively unstable one. At the end of a roll the pendulum would have a direction at right angles to P K, and if the angle between the free surface of the grain at P and P K is greater than the angle of repose, shifting will ensue.

The chief value of this method of Professor Greenhill lies in the means which it affords of indicating the stresses on any object liable to shift in the vessel; thus, at the end of a roll, a package of cargo is urged out of its place by a force given by its weight into its distance from K, divided by G K, and acting in a direction at right angles to the distance.

In the case of cargo stowed in the 'tween decks, the ratio of this distance to G K is practically unity, and hence the upper tier of bags of grain will, if there be room to shift, be urged out of their position by a force equal to their weight. This force having a vertical component, the resultant motion will not necessarily be downwards. It is, therefore, very important that all cargo which does not stow close up to the beams should be shored down. More especially is this necessary in sailing ships carrying ballast. In grain-carrying steamers it is a common practice to block off the cargo in the 'tween decks by means of sacks of grain sloped up, instead of building a transverse

bulkhead, with the inevitable result that, if bad weather is experienced, the sacks of grain simply jump out of their places, in virtue of this disturbing force.

Referring to the formula for determining the quantity of cargo that can shift, and applying it to the two vessels in question, suppose now that, in both vessels, the longitudinal bulkhead extends only as high as the beams, and that in both there is a free grain surface in the lower holds and 'tween decks 6 in. below the underside of the respective decks, and let the length of the free grain surface be 50 per cent. of the length of the vessel; then, using the formulæ before-mentioned, the weight of the cargo that can shift in steamer A will be 78 tons and the distance 21 ft.; the shift of the C.G. will be—

$$G\,G' = \frac{1638}{5900} = \cdot 277 \text{ ft.};$$

this will produce an inclination of—

$$\text{Tan}^{-1} = \frac{1638}{\cdot 67 \times 5900} = \cdot 414 = 22\tfrac{1}{2}^\circ.$$

In steamer B the weight of the cargo that can so shift will be 87 tons, and the distance it is shifted 21 ft.; the shift of the C.G. will therefore be—

$$G\,G' = \frac{2001}{5730} = \cdot 35 \text{ ft.};$$

and the inclination produced will be—

$$\text{Tan}^{-1} = \frac{2001}{1\cdot 5 \times 5730} = \cdot 233 = 13\tfrac{1}{4}^\circ.$$

If instead of being but 6 in. below the respective decks the grain surface is one foot below, then in steamer A the weight of cargo that can shift will be 162 tons through a distance of 21 ft., producing an angle of heel (supposing M not to shift) of $40\tfrac{3}{4}^\circ$. In steamer B the weight of cargo that can shift will be 162 tons through a distance of $23\tfrac{1}{2}$ ft., and the angle of heel will be 24°.

If, however, the longitudinal mid-bulkhead be absolutely grain-tight, then the quantity of cargo that can shift, its moment, and the angle of heel produced, will, in the two cases for steamer A, be but $\tfrac{1}{4}$ of the former quantities, the angles being $5\tfrac{1}{2}^\circ$ and 10°, while for steamer B the angles will be $3\tfrac{1}{2}^\circ$ and 6°. Thus, while shifting is less likely to occur in the narrow and deep ship, than in the broad and shallow one, yet if it does take place the effect is much greater. In other words, large stability conduces to shifting, but minimises its effect. Small stability retards shifting, but accentuates its effect.

It will, I think, be allowed that it is not difficult for a shipmaster to satisfy himself before sailing as to the conditions under which any bulk grain is likely to shift, and to adopt suitable measures. Surely this course of procedure is only, in the language of the Grain Carriage Act, a "necessary and reasonable precaution." Yet for reasons which are hardly obvious, it is never adopted, and notwithstanding the many

admirable and intensely "practical" rules and suggestions for the safe carriage of grain cargoes formulated by underwriters, shipowners, and seamen, vessels continue to be laden and sent to sea in a condition, as regards this stability, which simply conduces to foundering.

It will be seen that, even in a vessel with small stability, so long as the middle line bulkhead is grain-tight, the angle of inclination produced is but small. When shifting occurs at sea, the effect is usually to cause a large angle of permanent heel, and this is either of gradual growth, or may occur suddenly. When, then, the angle of heel slowly increases, the inference is that the mid line bulkhead is leaky; and when the angle suddenly increases, it is due to the filling pieces fetching away, or to a permanent displacement of some other part of the bulkhead.

In order to deal rapidly and effectively with a shift of cargo, measures should be taken while loading. The usual practice is to leave vacant space in the ends of the vessel. A better plan is, I think, to fill the ends and to leave a vacant space, properly bulkheaded off, in the lower athwartship reserve bunker, and to have at least twice the quantity of grain in bags that can possibly shift, stowed in the 'tween deck, in the vicinity. In the event of a shift of cargo, bags of grain could be transferred to windward and downward, thereby correcting the list rapidly, and increasing the G.M.

It is a much debated question, what is the minimum height of metacentre for any given vessel carrying a homogeneous cargo? The answer I submit is, that height which will ensure a positive stability after the greatest possible shift of cargo. In other words, if steps are taken to ensure good stowage, and to have an absolutely grain-tight middle bulkhead, then the metacentric height may be anything, so long as it fulfils the above conditions. If, instead of fitting one middle line bulkhead, two were fitted, the moment due to a shift of cargo would only be little more than $\frac{1}{6}$th of that if no bulkhead were fitted at all.

Since grain-laden steamers possess so little stability—using this word in the quantitative sense, as indicating the amount of force necessary to capsize a vessel—it is somewhat surprising that advantage is not taken of the ballast tanks to increase the G.M. The general objection to this course is that it would mean shutting out cargo. Seeing, however, that steamers cannot carry their deadweight of grain, the difference between the weight of the cargo and the deadweight capacity might well be utilised in the form of water ballast. With the lighter kinds of grain this could be effected without either shutting out cargo or diminishing the bunker space, providing that the ballast tanks were of moderate capacity. We can hardly expect a shipowner to acquiesce in obtaining stability by a diminution of the freight-earning capability of his vessel, as would be the case were cargo shut out; but we may reasonably expect that

the better and cheaper method would be adopted. Yet one of the salient facts elicited by the official inquiries into the losses of grain-laden steamers is that water ballast is never employed in this connection. There is, however, some reason to fear that the practice of filling a ballast tank during bad weather is responsible for the capsize and foundering of not a few grain-laden steamers. The effect of a partially filled ballast tank is, I need hardly say, to reduce the effective metacentric height, and an angle of inclination is attained, under the action of comparatively small external forces, which may induce a dangerous shift of cargo. In the case of steamer A, when her after tank is half full, the effective metacentric height vanishes.

Under the existing system of loading vessels with bulk grain cargoes, there is no reasonable assurance that the cargo is either properly laden or that the vessel is sufficiently stable. As the losses of these vessels show, many must leave port in an absolutely unseaworthy state, without either the owner, agent, or master being aware of the fact.

Referring now to the vessels whose particulars are given in the Table, I should say that they all, with the exception of the *Leo*, foundered during the bad weather which prevailed over Western Europe in the winter of 1893-94, when no less than sixty vessels were posted as foundered or missing during a few weeks. It is plausible to attribute these losses to exceptionally heavy weather—or, to use the pious jargon of the bill of lading, to say they were the act of God. Comfortable as is this solution, it is at the same time not satisfying. Such explanations are not regarded as satisfactory in the case of structures ashore, and I fail to see why we should accept them in the case of ships at sea. It will be observed that of this group six were built before 1880, and one in that year. Five of these six were of that type known as the three-decker, and the sixth, the *Harlsey*, was a well-decker. All these six vessels have a high ratio of depth to beam, and therefore possess the well-known characteristics of such narrow vessels, among which is their small stability when laden with homogeneous cargoes which nearly, or just, fill them. Vessels of this type are, indeed, not fit for grain cargoes without ballast; yet, by referring to column 11, we find that ballast was not used in any case. As will be seen by comparing columns 7 and 8, there was ample displacement available for ballast without overloading. Considering that all these vessels had water-ballast tanks, the omission to utilise this ready means of obtaining stability is simply inexplicable, especially as all these vessels were notoriously tender. The *Harlsey* was a well-decker, and the *Sir John Hawkins* a part awning-decked ship of good proportions, and of quite recent build; her loss shows that even modern cargo steamers are not altogether exempt from the risk of foundering when grain-laden. None of these vessels had ever been inclined, and nothing definite was known as to their stability. The association which we nearly invariably find in

foundered grain-laden steamers, of great tenderness, empty ballast tanks, ample freeboard, and absence of stability data, is, to say the least, extraordinary. After investigating the causes of the foundering of these grain-laden vessels, it is difficult to avoid the conclusion that loading is a process of throwing cargo, of whose physical properties neither the owner nor the captain knows much, into the hold of a vessel, of whose stability they know less.

In order to lessen the present heavy annual loss of vessels engaged in carrying bulk cargoes liable to shift, we can either look to the State, or trust to educated shipping opinion to provide the obvious remedies. As regards grain-carrying cargo steamers of the usual type, we may reasonably require that, in the worst condition of lading, and after the greatest possible shift of cargo has taken place, the maximum value of the remaining G Z's shall not be less than one-fourth of the original maximum. Any such provision implies that the vessels would have to be inclined. We might also require that at the grain ports there should be some system of competent inspection, so that transverse and longitudinal bulkheads and feeders, &c., would be properly constructed. The Grain Carriage Act undoubtedly requires amendment, and I suggest that this should include the following:—No vessel should be allowed to load any grain in bulk, unless she has an official statement of her stability attached to her register. Properly qualified inspectors should be stationed at the grain ports, and loading not to commence till vessel has been passed. Lastly, it is high time that stowage and the principles of stability formed part of the examinations of officers. It is useless for naval architects to place data, in the shape of curves and tables, in the hands of men who are without training or education in practical physics. On this subject a distinguished naval architect wrote some years ago:—"The care in handling which modern ships receive is not equal to their requirements, and that one of two things, probably both, ought to happen: either ships should be built so as to possess greater stability when discharging or loading than some of the finest of them now possess, or else the competency of those who have charge of them should be better seen to."

Since these words were written many improvements have been effected in the design and construction of cargo steamers, and the modern cargo steamer leaves little to be desired from the technical point of view. As regards the final part of the foregoing authoritative utterance, little or nothing has been done for the Mercantile Marine in the direction of supplying higher technical education; and hence ships continue to be lost because they are, in too many instances, entrusted to those who do not realise or appreciate the existence and operation of physical laws.

APPENDIX A.

Some Foundered and Missing Grain Laden Steamers.

Name. 1	Built. 2	Length. 3	Beam. 4	Depth, moulded. 5	$\frac{D}{B}$ 6	Legal Free-board. 7	Actual Free-board. 8	Cargo. 9	Description. 10	Ballast used. 11	Bunkers. 12	Stability. 13	Remarks. 14
		ft. in.	ft. in.	ft. in.		ft. in.	ft. in.	Tons.					
Ossian	1876	284 0	34 2	26 0	·76	5 1½	5 10	2,580	Mixed Grain.	None.	100	Unknown.	Exempt ship. 125 tons bulk grain in excess of quantity allowed by B.O.T. plan and owners' instructions. G.C. Act complied with (see below).
Henry Anning.....	1878	264 0	33 2	23 2	·70	4 0	4 6	2,000	Barley.	,,	110	,,	Exempt ship. Not loaded in accordance with B.O.T. plan nor with Notice 6. G.C. Act complied with (see below).
Sir John Hawkins ..	1892	302 0	40 3	23 0	·57	9 0	9 4	3,827	Wheat.	,,	150	,,	Stowed in accordance with B.O.T. plan.
Harlsey	1879	260 6	34 8	20 7	·60	2 0	2 3	2,037	Barley.	,,	170	,,	Stowed in accordance with B.O.T. plan.
North Durham	1880	265 5	35 3	25 10	·73	4 3	4 6	2,630	,,	,,	170	,,	Loaded in accordance with G.C. Act. Shifted cargo twice, and foundered on second occasion.
Provincia.....	1877	271 0	33 5	24 4	·73	4 6	—	2,140	,,	,,	—	,,	Not loaded in accordance with G.C. Act. Shifted cargo, and foundered.
Amoor .... } sisters	1879	285 0	35 2	25 7	·73	4 7	5 0	2,590	Linseed.	,,	163	,,	Well equipped for grain cargoes, loaded in accordance with B.O.T. plan. Stability insufficient.
Leo ..... } sisters	1879	285 0	35 2	25 7	·73	4 9	4 5	2,800	Mixed Grain.	,,	180	,,	Not loaded in accordance with plan. Vessel overladen. Stability insufficient.

Ossian.—The question (said the Court) we have to consider is whether, when, under Section 5 of the Carriage of Grain Act, the Board of Trade have, on the application of an owner of a vessel, approved of a plan for the stowage of a grain cargo therein, it is competent for her master to depart from the directions of that plan, and load in accordance with the regulations approved. Having carefully considered the effect of Section 5 of the Act, we answer this question in the affirmative, although such a course may be inexpedient, and, as it was in this case, contrary to the express directions of the owner. We can find nothing declaratory in the Act to the effect that the plan of loading, when approved of, may not be departed from; nor is there anything contained in it from which this can be implied. Two exemptions from the precautions to be adopted are specified in the Section, and if a master duly complies with the provisions of either of them, in our judgment there will be no infringement of the Act. There are alternative courses that he may adopt, and we see nothing in the section to prevent him from adopting one in preference to the other. We are therefore of opinion that the master of the *Ossian* would have committed no breach of the Act if he carried barley in bulk in the 'tween decks, provided he duly complied with the regulations approved of by the Board of Trade, and from the evidence of the stevedores at Odessa it would appear that these regulations were complied with.

Henry Anning.—The master stated that he loaded according to the plan; but, inasmuch as admittedly all the grain in the 'tween decks was in bulk, he violated the conditions subject to which the plan was sanctioned. But Official Notice 6, issued in 1881 (made under Section 5 of the Carriage of Grain Act, 1880), authorises the loading of barley in bulk in the 'tween decks subject to the provision of feeders of sufficient capacity. The feeders of the *Henry Anning* being of sufficient capacity, Official Notice 6 was complied with. If, however, the plan approved by the Board of Trade in 1889 superseded Official Notice 6—in its application to the *Henry Anning*—then her cargo was not properly stowed, inasmuch as the precautions prescribed in the conditions annexed to the plan were neglected. Such precautions, although not specifically prescribed by the Carriage of Grain Act, were prescribed by the Board of Trade under Section 5 of the Act, and if they may be designated necessary and reasonable precautions, then the master committed an offence against Section 3 of the Act. If, on the other hand, the *Henry Anning* were a doubly exempted vessel—*i.e.*, authorised to carry barley in bulk in the 'tween decks by virtue of Official Notice 6, and also authorised to carry other grain partly in bulk by virtue of the arrangement of 1889 (although this purported to apply to all grain)—then she was in the position of being free to trade with all the privileges of both classes of exempted vessels, unfettered by the obligations of the second.

APPENDIX B.

Various Offences against the Grain Carriage Act for which Convictions have been Obtained during the First Half of 1894.

NATURE OF INFRINGEMENTS.

1. No shifting boards were fitted in the thwartship bunker, and the deck beam fittings were not secured.

2. No shifting boards were fitted in the hatchways.

3. The feeder to the thwartship bunker and the space in 'tween decks above same contained less than 2 per cent. of the underdeck cargo.

4. The feeders upon the bridge deck were deficient. The feeders to the main hold contained more than 6 per cent. of underdeck cargo. The compartment at the after end of main hold had no feeder. No shifting boards were fitted in hatchways. In the after hold the shifting boards did not extend down to the tunnel. Several beam fillings were omitted. Shifting boards were not grain-tight. All the inner deck hatches were on. (The cargo was barley.)

5. No. 2 hold and 'tween deck above were filled with cotton seed and barley, the deck openings being closed. No. 3 hold and 'tween decks were filled with beans in bulk, and had no feeder. (These spaces were under bridge.)

6. The shifting boards were not complete up to deck. The compartments were neither filled nor covered by grain in bags as required.

7. The shifting boards in Nos. 2, 3, and 4 holds had open spaces, and the feeders contained less than 2 per cent. The Nos. 1 and 4 holds were neither filled nor covered with statutory quantity of grain in bags.

8. One 'tween deck space and the hold beneath filled with cotton seed—all openings in the 'tween decks being closed, and no feeder provided.

9. The shifting boards commencing at 3 ft. to 5 ft. above keelson and terminating 4 in. from deck.

10. In Nos. 1 and 2 holds the shifting boards for part length were 5 ft. from keelson. In the 3 and 4 holds the shifting boards commenced at 3 ft. to 9 ft. above shaft tunnel. No beam fillings.

11. Shifting boards had open spaces, and were in bad condition; they were not carried up in the hatchways and had no beam fillings.

12. Carrying in the 'tween decks grain in bulk other than was necessary for feeding the cargo in the lower hold.

13. The after hold was partly filled with barley—the statutory quantity of grain in bags not being over same.

14. The shifting boards were not carried down to the keelson or shaft tunnel, and had openings at other parts.

15. Insufficient feeder space to the thwartship bunker.

16. The holds were partly filled with linseed and barley, without the statutory quantity of grain in bags upon top of same.

17. In Nos. 2 and 3 holds the shifting boards stopped from 10 in. to 12 in. beneath deck—nor were they filled in the hatchways. In No. 4 hold they were not extended down to tunnel.

18. Shifting boards were not fitted in the hatchways at places. There were no beam fillings. Generally, the shifting boards were not grain-tight.

DISCUSSION.

Professor A. G. Greenhill, F.R.S. (Visitor): We are much indebted, I am sure, to Captain Kriloff for the valuable reference to the earliest paper on the subject brought before us by Captain Little—a paper in 1758 by Euler, entitled, "Examen des Efforts qu'ont à supporter toutes les Pièces d'un Vaisseau dans le Roulis et le Tangage"; and Euler might also have added, "Des Efforts qu'ont à supporter l'Équipage du Vaisseau," as Sir William White tells us vessels cease to be habitable long before they are unsafe. All who are interested in this subject will, I am sure, lose no time in consulting Euler's original memoir. The late Professor Jenkins solved this problem for all practical purposes when he investigated the maximum value of the stresses due to rolling which occur at the end of a roll. All that is required is to draw a line as shown in Captain Little's diagram, Fig. 4, Plate LVIII.—a line L K, drawn from L, the centre of oscillation of the ship, and perpendicular to G L, to meet in K the line through G, the centre of gravity in the horizontal direction. We are taking the usual liberty which the naval architect does with the vertical, when he draws his ship vertical and inclines the water. If G K represents the true horizon, then the apparent horizon of any point in the ship is obtained by joining that point with the point K. A pendulum model of a ship constructed in this manner, with cups or vessels of water placed in different positions, shows very clearly the variations of internal stresses at different points of the swinging body. Old-fashioned wooden men-of-war, and modern French ironclads too, are built with a considerable falling in of the sides. I have never seen anywhere any reasons for this rule, any more than the reasons for the raking mast of a ship, but there must be reasons which are familiar, probably, to shipbuilders in this room, and I should feel much interested in hearing them, especially as I think they must depend on the principle indicated on page 375 of the paper which Captain Little has brought before us.

Mr. B. Martell (Vice-President): Sir. Edward Reed and Gentlemen, I regret very much that I had not an opportunity of seeing this paper till within the last hour. It would have pleased me very much to have read it and studied it, and I think I should then have been prepared to say more about it than I am at present able to do. Still, I have great pleasure in placing my remarks before the members of this Institution, and at the same time thanking Captain Little for giving me the opportunity of doing so, and likewise in expressing our thanks for the care he evidently must have taken in preparing his paper. I cannot say, however, that I agree with him in many of his deductions here. Now, in the first place, I notice that throughout this paper there is a strong condemnation of the action of the Board of Trade. The members of the Board of Trade and myself do not agree in all things; but at the same time, having had a very great deal to do with them in the last few years, I believe they are doing the utmost in their power to ensure the safety of ships under all circumstances, and likewise to consult the interests of shipowners in matters dealt with by them. I remember, when the Grain Act was brought into operation, a deputation of shipowners attended at the Board of Trade and consulted Mr. Chamberlain, who was then President, with regard to some changes as to loading a portion of the cargo in bags. Mr. Chamberlain was very complimentary to me, and said that before he came to a conclusion he would be glad if the shipowners would request me to come up with them, so that we might have a conversation together. I did so. I went up with some shipowners of the City of London, and had a consultation with Mr. Chamberlain, and I must say I found him not only a very capable man in dealing with the question, but likewise very desirous of meeting the shipowners in what they proposed to him, if it could be done consistently with the technical advice given

him, which would assure him, as far as possible, that it could be done with safety. There is one thing Captain Little has rather omitted, and I trust I shall not be considered egotistical if I refer to it, and that is that, when a large number of vessels were being lost yearly, amongst which a considerable number of steamers were lost from foundering—one vessel was turned over on her broadside loaded with coals, which is a cargo we do not expect to shift so much as grain—I thought then the time had arrived when this question should be thoroughly investigated, and it was investigated in my office, under my supervision. This was done, and I had the honour of reading a paper here embodying the results. That paper was designated "The Causes of Unseaworthiness in Mercantile Vessels"; and those causes were largely found to be due to instability from improper proportions, such vessels having too great a depth in relation to their beam. I had curves of sections got out showing the amount and range of stability, and I endeavoured to draw attention to the great desirability of increasing the proportionate breadth of merchant ships. I have no hesitation in saying that that paper produced a very great effect, as was mentioned to me by the late Mr. William Denny, and also by Mr. Inglis, of the Clyde, who said it really opened up a question which we all had not given sufficient attention to, and which showed the extent to which many of these losses could be attributed. Since that time the proportionate breadth of ships has been very much increased, adding very considerably to their safety; and very many improvements in other directions have been made, also adding to the safety of ships; and I do not think that this is altogether the time to startle the public with an idea that ships are lost, to the same extent that they were at one time, from causes which are preventible. I find that even in the list given here the first-mentioned vessel was twenty years old. She had been sailing for twenty years with perfect safety, and it is very reasonable to suppose that a want of care had been exhibited by the captain, or those in charge, in loading that ship, a thing which will occur, and which we must be prepared for. You cannot expect the greatest care to be taken by all the captains and stevedores, or the greatest knowledge exhibited by them in stowing vessels, and consequently losses will occur from this cause alone. This ship was one of those I alluded to at that time—a ship 284 ft. long, 34 ft. 2 in. beam, and 26 ft. depth of hold. Builders generally would not think of building a ship of these proportions at this time. The next ship is eighteen years old, the next fourteen, the next seventeen. What I want to show is that these are particulars I called attention to in the paper referred to. Attention was also called to the loading of such vessels, and particularly when carrying homogeneous cargoes. In loading these cargoes an opinion was expressed of the necessity of running up the water ballast tanks, or of leaving out a portion of the cargo between decks, or of carrying ballast of some other kind in these vessels. I may say that the losses of mercantile ships have been gradually decreasing—not increasing—decreasing to a very considerable extent, I am glad to say, and that, too, owing to two or three different causes: one is the difference in the proportions of vessels alluded to, and which ensures greater initial stability; and another cause is the effect of the Load Line Act. No doubt that likewise has had a beneficial influence. But when a writer comes before us and tells us what we ought to take as the minimum metacentric height of a ship, then all I can say is that he must have great confidence in his judgment, because I do not hear professional men willing to pin themselves to such a hard and fast opinion as that. Professor Biles told us this morning that he was himself on board of a ship that had a very trifling metacentric height, and that she was perfectly safe. Mr. Little says:—"Both in design and management the sailing ship of to-day is a negation of many of the more important principles of safety." I contest that—I challenge that statement with regard to the sailing ships of to-day. There were never ships built like them for safety in former times. Every year they have gone on improving—

the model, the proportions, the rig of sailing ships are all improved, and I may say that I believe the sailing ships of to-day have been brought to the highest state of perfection, such as was never before attained. I know that the question of dismasting—and many cases of dismasted vessels have been alluded to, particularly in large sailing ships—was gone into most carefully, and I, in connection with my assistants at that time, reported on these cases to the Committee of Lloyd's Register, and these reports were issued publicly, in order to advise shipowners with regard to the loading of these large sailing ships. It was a question of loading—it was fully realised that the enormous percentage of these ships had great proportionate beam, and deadweight was all put in the hold, without a sufficient quantity in the 'tween decks to raise the centre of gravity of the ships. It was after those six or eight serious cases of dismasting in that year that shipowners gained experience, and since that time there has been a comparatively small number of dismasting cases as compared with what there used to be in previous years. With regard to issuing a certificate as to the amount of stability a ship should have, that is perfectly out of the question—it is a thing you cannot do. When the Load Line Committee had their meetings (our present Chairman will bear me out, because he was Chairman of that Committee, and I am proud to have the opportunity of saying that he conducted it with the very greatest amount of ability) we took into consideration the question of bringing in the element of stability, and we found that it was perfectly impossible to do it. Merchant ships are built for various purposes of trade. In one year they may be loaded with a homogeneous cargo, of such small specific gravity that when they are filled full they are not brought down to their load-line. Again the cargo may be of iron or copper ore, &c., which, if placed at the bottom of the ship, which is often the case, may cause undue stability, and thereby cause excessive violent rolling, sufficient to roll her masts out in heavy weather. With regard to underwriters drawing up rules for grain cargoes, I do not know, but perhaps Captain Little will be able to inform me, of any such rule of underwriters in this country. The American underwriters have done so, and have had such vessels surveyed; but, unfortunately, I do not think any better effect has resulted from that than from the rules we have. "Well-decked" ships were really, from an underwriting standard, the safest vessels, which we attributed to a great extent to the fact that there was no lower deck laid, and therefore, with a grain-laden cargo, you could fill the hold of the vessel, whereas in two-decked vessels the difficulty of trimming the cargo in the angles under the beams at the sides of the ship caused vacant spaces to be left; consequently, when a ship after leaving port met with heavy weather, the cargo would shift unduly into one angle, on one side, and the other angle would be empty. The only means of preventing that was to have these feeders which Captain Little refers to, and which doubtless do a great deal of good. But at the same time I still think there is a far better means of preventing shifting of homogeneous cargoes, and that is to leave out the lower deck. Have a tier of beams fitted, but leave out the deck, so that the hold may be filled full in the same way as in the well-decked ship, while at the same time putting an additional strength to compensate for the deck being omitted. I think that will add very much to the safety of ships in carrying homogeneous cargoes, and it has been sanctioned in classed vessels by Lloyd's Register Committee. I regret that there is not a little longer time at one's disposal, so that one could deal more fully with this important question. At the same time you will allow me to express my thanks, in which I am sure you all share, to Captain Little for the intelligent manner in which he has dealt with this subject.

Mr. Archibald Denny (Member of Council): Mr. Chairman, I only want to say one word, rather in extension of what Mr. Martell and Professor Biles have said as to the proper amount of metacentric

height for any vessel. I quite agree with Mr. Martell that you can lay down no rule. Perhaps no firm has taken a greater interest in this question than my own, and we have always been most careful to say that it is not possible to lay down any rule. We mention ·8 of a foot as a suitable figure, but since I read my paper at the Paris Summer Meeting the instrument I then introduced to the notice of the Society has been largely used, and we have one case of a vessel, which I should like to mention, carrying a general homogeneous cargo, an ordinary cargo boat 320 ft. long. The instrument was used at least once on each voyage, sometimes twice, and that vessel sails habitually with nothing more than ·6 of a foot. The captain reports her behaviour as admirable in a seaway, and that she is, in every way, comfortable and safe. Our old figure of ·8 has thus had ·2 knocked off it; but Professor Biles now knocks off the remainder altogether. I am delighted to find that Captain Little is one of a class which is growing rapidly in number, a class of captains in the Mercantile Marine who really take an interest in scientific subjects of this kind. The more of these captains we have, the more valuable our deliberations will be, and the better it will be for the shipping of Great Britain.

Mr. G. A. Laws (Associate): Mr. Chairman, I do not think anyone will accuse me of any great desire to defend the principles of the Grain Act, as applied to British shipping; but I think, in considering a paper of this kind, it is only right to remember that in 1880, when the Carriage of Grain Act was framed, steamers loading grain rarely exceeded 1,000 tons, and had 'tween decks. Now we have steamers carrying 5,000 tons of grain in one depth of hold—that is the class of vessel which has had to be dealt with in the interim, when, as Captain Little says, these separate notices by the Board of Trade were issued; but it is due also to the Board of Trade to say that these notices relieved the shipowner, and were on the side of safety. For instance, one of the most important was issued to modify the rules for stowage of barley, which, having regard to "shifting" only, is one of the safest grain cargoes to carry; but at the same time it is one of the unsafest when you consider the question of "stability" alone. The first notice of the Board of Trade modified the Act in this respect, that, instead of having to carry part barley in bags which unduly raised the centre of gravity of the cargo, you can now carry it all in bulk, provided you have proper feeders, &c. I also think Captain Little is not quite accurate in attributing so many grain ship losses to shifting cargo. My old and esteemed friend Mr. Martell has just told you that there were other potent causes, and those who have searched for the causes of shipping losses in the grain trade have come face to face with this: that before any shifting of the cargo commenced the high deck ventilators, which were never intended for grain cargoes (though grain merchants insist on having them), were washed away, and the water rushing in soaked the grain on the lee side, the vessels then listed and capsized. I think it will be found that more grain vessels have been lost in that way than by the initial shifting of the cargo. There is another point raised by Captain Little; he appears to think care is seldom taken to fill up the water-ballast tanks. He is quite wrong there. The water-ballast tanks are constantly filled under light grain cargo. When you have the centre of gravity raised to the highest degree, the ship may be full of oats or seed, but not down to her load-line. You can then run up the water-ballast tanks to increase stability, and they always do it. There is only one other point, which was also partly dealt with by Mr. Martell, and that is on page 379, where Captain Little suggests that "no vessel should be allowed to load any grain in bulk unless she has an official statement of her stability attached to her register." That would be a drastic notice, if you like; and Captain Little should tell us what stability he means. Is it the initial stability of the empty ship, or when laden with maize, wheat, rice, rye, barley, oats, or poppy seeds, or even nut kernels? The specific gravity is different in each case, and you would require a curve for each of these. I will say no more on this subject, except that I think he will find there is

now every attention paid to these things by the shipowners' mutual insurance associations. They have gone very carefully into stowage of grain with the Board of Trade, and have done their very best to point out and remedy most of the evils that caused losses in former years.

Mr. G. H. Little (Visitor): Mr. Chairman, I shall be very brief in my remarks. It is really a very great honour for me to come here with such an audience as this, and also, I must say, I am gratified that the paper has received the criticisms it has from such a distinguished authority as Mr. Martell. Nobody recognises more than I do the value of his remarks. I may say that I have studied his papers in the Transactions of this Society with very great advantage, and I am sure many other seamen have done the same. I did not make reference to Mr. Martell's papers, because his work is so well known that it was almost superfluous to do so; whereas the work of the gentlemen to whom I did refer is not so well known. The loss of life at sea is very much less because the type of ship has improved; the building is better, and there are not those cases of unseaworthiness. My point is this, that we want to do something to better the education of ships' masters and officers. About this question of the G. M., we know from the investigations of the late Mr. Denny and others that it is quite possible to have vessels sailing successfully with a negative G. M., so long as the cargo does not shift. I take it Mr. Denny would not say for a moment that negative G. M. is advisable in the case of a cargo like grain. With regard to the question about sailing ships which Mr. Martell raised, I quoted the opinion of a well-known Liverpool underwriter, Mr. Wallace—one of the most experienced underwriters—who has publicly stated what I said, and—with due deference to Mr. Martell—that they are undoubtedly the great causes why these ships founder as much as they do. The Chamber of Commerce of New South Wales issued a special circular with reference to the great loss of coal and ballast-laden ships. Our British insurance corporations do not make regulations for loading in foreign ports such as are made in Montreal, San Francisco, and Hong Kong; but even these regulations have to be approved by the Board of Trade, and I think, with all due deference to the Board of Trade, that it is most unwise to sanction them officially. I have already dealt with the question as to G. M. raised by Mr. Denny. Mr. Denny says you cannot lay down a rule. Of course, I do not profess to come here and put my opinion in the face of that of so many professional gentlemen. I put it before you tentatively, and I am quite willing to leave the question to such members as Mr. Denny, who knows more about it than I do. So long as the cargo does not shift, that is the great thing. With reference to the remarks of Mr. Laws, Mr. Laws rather approved the Board of Trade, and it is very good and comforting to me to find the Board of Trade now lying down with him in such an amicable way. The sight of the official lion lying down with the commercial lamb in such comfortable relationship is distinctly edifying. With regard to the ventilators being carried away; of course, those ventilators were fitted by the Board of Trade's sanction. They have undoubtedly been a cause of loss of life. From my own experience in cargo steamers they are an abomination, especially those just under the bridge. About water ballast; Mr. Laws will recollect that, some few years ago, we had a controversy on this subject in a North of England shipping paper, and I myself opened the case, and I think one or two eminent shipowners and naval architects dealt with it; I do not think I can do better than to refer to Professor Jenkins' conclusions, which admirably show that it is a very dangerous thing to open a ballast-tank cock in a seaway, or even at sea at all. I think, gentlemen, that is all I need say, and I thank you very much for the reception you have given to this paper.

The Chairman (Sir Edward Reed, K.C.B., F.R.S., Vice-President): Gentlemen, I think we shall all be desirous of thanking Captain Little for contributing this paper, that is of a type, at any rate, which,

although not free from criticism—just and proper criticism—nevertheless illustrates the great interest that officers of the Mercantile Marine take in matters of this kind. I think the paper reflects the greatest credit upon the author, and that the manner in which he has replied to the points raised against him is simply admirable. Professor Greenhill asked a question, and got no answer. I do not know whether I can answer him, but I will try. He asked why it was that, in the French Navy of to-day, and in former times, the sides of ships had a great deal of "tumble-home." The reason was simply this, and I never knew of any other; in the old days you required the breadth of the ship about the water-line, to get your flotation and stability, and you did not require it high above the water-line, because you only wanted light guns, tier upon tier, and obviously, if you kept the ship with a straight, vertical side, all your beams would have been greater, your decks more extensive, and you would be building a quantity of ship that you did not want. The only reason it was made narrow was because there was no occasion to make it broad. In the case of the modern French ironclads, there is another reason, and that is, that the French have sought to attain right ahead and right astern fire by means of projecting batteries; and, obviously, the more tumble-home you give to the side of the ship the more easily you get that fire, and with the least projection of the battery. I may, perhaps, be allowed to say, on the other point (and I think I shall have the corroboration of most of my old Admiralty friends here) that, with regard to the supposed novelty of ships having no metacentric height, in the old days there was only one calculation of stability made for a ship of war, and that was to find if she had stability, and how much she had, at an inclination of 7°. If she was found to be all right at 7°, she was deemed to be all right, once and for all. The simple reason was that the ships were high-sided; and even in those vessels with a great deal of tumble-home, the statical stability increases at a considerable angle before you reach the maximum.

PROCEEDINGS BEFORE READING CAPTAIN LITTLE'S PAPER.

The President (the Right Hon. the Earl of Hopetoun, G.C.M.G.): Gentlemen, I have received a very important summons to go to the Admiralty to meet Mr. Goschen, and I would ask you to excuse me if I run away almost immediately, and if I request Sir Edward Reed to occupy the position of chairman for the remainder of the sitting.

Sir Edward Reed, K.C.B., F.R.S. (Vice-President): I think, gentlemen, that it will be very excusable if I make a breach in our usual arrangements, and propose, as his Lordship will soon have to leave us, that a vote of thanks be accorded to him for his services in the chair before we take the next paper. I know I shall only give expression to the universal feeling of our members and of our visitors, if I say that this vote of thanks has never been proposed with more appropriateness or with more satisfaction and pleasure than it will be on this occasion. Our first President became our President when he was First Lord of the Admiralty, and his being First Lord of the Admiralty when he became President brought an immense amount of influence to the Institution, and gave us a very prosperous start. I can say for myself, having been closely associated with the late Sir John Pakington, afterwards Lord Hampden, that the Institution is more indebted to him than to any living man for its early prosperity, and that I shall never think of him, and never do think of him, without a sense of gratitude, and a very great sense of gratitude, for his most friendly services to this Institution. He was succeeded by a nobleman who, in Parliament, had taken a lively interest in naval matters, Lord Ravensworth, and who, by his consistency in his devotion to the Institution, and by his invariable courtesy, and by the skill with which he presided over our meetings, won golden opinions from all of us. He was succeeded, most appropriately as it seemed to us, by Lord Brassey, who had very special claims upon the appreciation and confidence of naval architects and naval officers everywhere, because he has devoted the greater part of his life, and no small part of his means, and a very large part indeed of his energies, to making himself, as far as possible, a master of naval science and naval practice; and I confess that, when he accepted the appointment to Australia, I did my best to persuade him not to resign the Presidency of the Institution, but to retain it, and do his work by proxy except at the annual meetings, and then to come over for a holiday once a year and preside over us. Well, the distance is not a very great one, it is only half way round a little bit of a planet like this, and I thought, in these days, he might have managed it, and I urged the point upon him because I did not see how we were to replace him very successfully. I think we are now in a position to know that even Lord Brassey, valued as he was and is by us, could be spared, because he has been succeeded—owing to the wisdom of the governing members of the Institution and of the Institution itself—by a nobleman who has shown this week that he is able to preside over us with the greatest possible advantage to us. I think his opening address to us was a model of what we are entitled to hope for from a non-professional President, and I think his speech at the dinner (it is of no use saying that I think so, because it is a matter of general knowledge) deserved, as it was received with, universal admiration and applause. I will take the liberty, in concluding these remarks, which are

intended to recommend this vote for your very cordial acceptance, of saying that, just as in the commencement of our proceedings a First Lord of the Admiralty became our President, so I hope before very long that our President will become First Lord of the Admiralty. We have no direct and ready means of properly and fully thanking Lord Hopetoun for his services ; but we may console ourselves in some small degree by the reflection that he is one of those young and able statesmen who are marked out for future high office in this country ; and that, if the good old principle of putting people into offices about which they know nothing is abandoned, and if we have men appointed for efficiency and competence, and ability to discharge the high duties of the State in the high offices of the State, we may all feel that Lord Hopetoun will not have been wasting his time altogether by presiding over us. I hope his Lordship will feel that the training is a very appropriate and good one, and I am sure it will have the effect of showing to him, first, that the subjects with which the men who will then be his subordinates have to deal are very difficult, very intricate, and at the same time are discussed with the greatest fairness in this Institution, and that everything that men can do, whether as naval officers or naval architects, is done here for the purpose of promoting the public interest, the welfare of our country, and the advancement of the great naval services, both public and private. Gentlemen, I hope you will most cordially pass this vote of thanks to his Lordship for his admirable and generous services in the chair during these meetings.

Mr. B. Martell (Vice-President) : I have very great pleasure indeed in seconding this resolution. I feel that there is really nothing to be said after the eloquent remarks of Sir Edward Reed, and the way in which he has expressed our appreciation of the manner in which his Lordship has presided over us. But the few remarks I may make may perhaps serve to emphasise what Sir Edward Reed has said, whilst I am sure you would like anything said which would express to Lord Hopetoun the high appreciation we have of the manner in which his presidency over us has been conducted. As Sir Edward Reed has said, when Lord Brassey resigned the position of President, we had much discussion with reference to his successor, and some difficulty arose as to whether we should find one combining those qualities possessed by the previous Presidents of this Institution. We all feel we may congratulate ourselves on our great good fortune in having had Presidents to preside over us who have had all the qualities essential for that service. But our experience, which we now give expression to, has shown us that our noble President has all those qualities to commend him to us, and we feel sure that in the manner in which we shall be presided over, the carefulness, the courtesy, and kindness and ability which have always been displayed by our Presidents will be continued, and that the continuity of those excellent qualities in our President will remain unbroken. I therefore have a great deal of pleasure in seconding this proposition.

The resolution was carried by acclamation.

The President (the Right Hon. the Earl of Hopetoun, G.C.M.G.) : Gentlemen, I only wish that I could do justice to the very eloquent manner in which this vote of thanks has been proposed by Sir Edward Reed and seconded by Mr. Martell, and to the manner in which it has been received by you. When Sir Edward Reed reminded you of the distinguished men who have occupied the chair of this Institution in past years, mentioning the names of Sir John Pakington—who was a relative of my own—Lord Ravensworth, and Lord Brassey, I felt that I was a very unworthy successor of such men, but I can only assure you it is my extreme desire to do my duty and to give you satisfaction. One of the most important duties of the Chairman is to keep order at the meetings, and if he sees the discussion is running a little bit off the rails, to gently, and with what tact he possesses, push the

machine back into the proper road again; but matters have gone so quietly and so smoothly during our present session that my duties in this direction have been practically a sinecure. Sir Edward Reed has been good enough to map out a very ambitious future for me—a far more ambitious one than I would ever have dared to map out for myself. I have always taken the greatest interest in everything connected with the Navy. I may tell you in strict confidence that I am a very bad sailor, and I prefer a warship when she is safe in dock to going on board of her when she is at sea. But, although I am a bad sailor, I have always taken the utmost interest in everything connected with the Navy, and if it should be my good fortune, either in the humble position which I am at present occupying as attached to the Admiralty, or in any future post of a more important nature to which I may be called, to be able to be of service to my country, I shall feel that I have been fully rewarded for any trouble which I may have taken in the matter. Gentlemen, I thank you most sincerely, and I apologise to you for being obliged to leave you.

CONCLUDING PROCEEDINGS.

Mr. H. Morgan (Vice-President and Treasurer): We have now reached the end of those subjects on which it is most natural and desirable that we should not agree, and have arrived at that part of our programme described as "concluding proceedings," on which I am sure we shall all agree. One item you are aware has already been disposed of, and that is the vote of thanks which was so cordially awarded to our President before he was obliged to leave the meeting. It now becomes my agreeable duty to call the attention of the meeting to the very great obligations which we are under for the use —the gratuitous use—of this very splendid hall, which, I may remind you, is lent to us by a society that we have nothing to do with, towards whose revenue we contribute nothing; I mean the Society of Arts. Possibly some of our younger members—and it is very natural—may be under the impression that this hall belongs to us—it fits us so beautifully as to its locality and size, and it is so suited to our proceedings in every way. I may remind you that this is the thirty-sixth year that we have met here, and I think, in a sense, we have grown into it. We began in this room thirty-six years ago when we could not take care of ourselves, and could not afford any such place as this to meet in. We have grown to our dimensions of 1,200 members, with an increase this year of 82, in this room. We have met here all these years, and during the whole of that time the Society of Arts have annually placed this beautiful hall at our disposal. It may be pardonable on this occasion to cast a glance forward and imagine the time, which is perhaps coming, when we shall be obliged from the necessities of our growth, which seems to be always advancing, to look elsewhere for some larger place; but whenever the separation comes from this hall it will, I am persuaded, arise from our own necessities and not from any change in the friendly disposition on the part of the Society of Arts. I have to propose that our very cordial thanks be given to the Society of Arts for their continued kindness in allowing us the free use of this beautiful room.

Mr. J. Macfarlane Gray (Member of Council): I have much pleasure in seconding this resolution, for I feel that we are indeed much indebted to the Society of Arts for our accommodation, free of charge, in this beautiful hall. So agreeable have been the relations and, for more than thirty years, so stable our position, that I am thinking ours must be another instance of the practicability of perfect safety along with negative metacentric height, about which Professor Biles has been telling us. I hope there may never be any occasion to leave. I cordially agree with Mr. Morgan's remarks, and I have much pleasure in seconding the motion for a vote of thanks to the Society of Arts.

The resolution was carried unanimously.

Rear-Admiral FitzGerald (Associate): Gentlemen, it is my pleasing duty to ask you to record a vote of thanks to the Council, for the admirable arrangements which they have made for our comfort and convenience during these meetings, and, especially I may say, with regard to the general policy of holding a Summer Meeting, which I feel sure you all appreciate so highly. At the Summer Meetings our instruction is diluted with a little pleasure, which makes it all the more easy to swallow

and digest. We had one in Paris in June last, and you will all fully endorse what I say when I venture to express the opinion that those members who did not go to Paris were very sorry for it, after they heard of the nature of our entertainment. We are now invited to a meeting at Hamburg. You have all heard, no doubt, that the Council, with the advice of their able Secretary (whom I hope you will allow me to mention, because I do not know whether there is to be a separate vote of thanks to him), have accepted this invitation. We all know that it was largely owing to Mr. Holmes' hard work, tact, and ability that the success of our Paris meeting was assured. There are a great many who do not know the time and trouble he took in the matter, but those who do know fully appreciate it. We are assured that we shall receive in Hamburg as hearty a welcome as that which was given to us in Paris. With this vote of thanks I beg to couple the name of Admiral Sir John Hay, whose good work, whose ability, and whose unvarying courtesy all who know him so highly appreciate.

Mr. J. R. Fothergill (Member): I rise to second the vote of thanks so ably proposed by Admiral FitzGerald. Sir Edward Reed, in proposing a vote of thanks to the President, alluded to the happy judgment and good fortune of the Council in being able to secure for the Institution a President, in all respects, so suitable for the office, and I think we might take this opportunity to congratulate the Council on their choice. Those members who have the pleasure to know members of the Council must fully realise, and appreciate, how thoroughly their hearts are wrapt up in the best interests and welfare of this Institution. I believe that on no occasion do they spare themselves in doing what they think may be desirable and advisable for the best interests of this Institution. There is one other point I should like to mention: I think we may heartily congratulate the Council on the great changes that have taken place, in that they have been able to print and issue the papers, so that members, who desire to apply, can obtain copies some days before the meetings, giving greater opportunities of entering heartily into the discussion with benefit and advantage to us all. I have very great pleasure in seconding the resolution.

The resolution was carried unanimously.

Admiral Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S. (Vice-President): As a very old member of the Council, I rise to return thanks for my colleagues. I do so with much satisfaction. I thank Admiral FitzGerald especially for the kind manner in which he has just alluded to the work of the Council. He has congratulated the Council on the work they have been enabled to do. I must say it is only for the Council of this Institution to be summoned by our excellent Secretary for them to attend in great numbers. They come from the ends of the earth, and they perform their duties and disappear again. When they are wanted they are there. If they are wanted for Committees, they attend most zealously to them, and there is not a person who belongs to the Council who does not devote his best energies to the services of the Institution. I am sure that my colleagues are with me when I say that we should be probably not quite as efficient as we are if we had not the ablest and best Secretary that ever a society possessed. I am sure I should be doing injustice to your feelings, and to the feelings of the Council in general, if I did not ask you now—with your permission, Sir Edward Reed, to offer a hearty vote of thanks to Mr. Holmes for his consistent and zealous labours, and for the very great ability which he devotes to our service.

Mr. Archibald Denny (Member of Council): I should like to second the vote of thanks to our Secretary, because I know the enormous amount of work he gets through. With regard to the remark of Mr. Fothergill about the papers, it is really due to your Secretary that we have got

them at this meeting in time. The members assisted; but there is no obligation on the members to send in their papers at an early date. In seconding this vote of thanks to our Secretary, I would say this: that I believe the best service the members could render the Secretary would be to press the Council to pass a resolution that members should send in their papers in time to have them published before the meetings. If that were done, the Secretary's work would be very much lightened; at present it is enormously increased by having to dun members for their papers. I heartily second the vote of thanks to our Secretary.

The Chairman (Sir E. J. Reed, K.C.B., F.R.S., Vice-President): As an old secretary of this Institution, I have very great pleasure in putting this vote of thanks to our present Secretary. I have always felt, since he has been our Secretary, very proud of him, because he is one of those gentlemen who knows the way to do very thorough work, and very hard work; and, at the same time, never seems to be under any burthen of work, but he is always ready to be genial and nice to everybody. Those are qualities which very few secretaries possess, which I, when secretary, never did possess, and never should, if I became secretary again. I hope that we shall pass this vote with very great cordiality, because it is saying nothing in reduction of the thanks which we have accorded to the President and Council, to recognise the fact that Sir John Hay so well expressed, that no President and no Council could be anything like so successful as they are in this Institution but for the commanding efficiency of the Secretary.

The motion was unanimously carried.

Mr. G. Holmes (Secretary): Sir Edward Reed, Sir John Hay, Mr. Denny, and Gentlemen: I do not think I can properly thank you for the exceedingly kind way in which you have spoken of my services. I am very proud indeed of the success of this Institution. I think it has been proved by the notice that has been taken of us by foreign countries and by their Governments, and by the immensely cordial support which is always given to us at every outport we visit. I think it is also proved by the great number of new members joining the Institution, in fact I believe we are only on the threshold of that expansion which is ultimately to be ours. But I do not, for one moment, believe that any part of that success is due to my efforts. I only do what I am told to do by the Council, and I believe that the success of the Institution is due to the fact that it fulfils a great public want; it promotes two of the greatest interests of the country: the welfare of our seaborne commerce and our naval defence, and I believe it is the wish of every member of this Institution, as it is one of the chief objects of the Institution, that we should serve those ends faithfully, and those ends alone. Whatever measure of success is due to my efforts is not due to me alone. I have been ably backed up by my small staff, and my best thanks are due to them for the faithful service which they always render, and for their diligent and efficient performance of any work they are called on to do. Again, gentlemen, I thank you heartily for your kindness, and hope we shall meet again in Hamburg in very large numbers.

OBITUARY NOTICES.

Dr. Peter Denny, F.R.S.E.

The Institution has lost, in the person of Dr. Peter Denny, one of its Vice-Presidents, and a member whose family was intimately associated with the very beginnings of steam navigation, and who was himself one of the most prominent shipbuilders of our time.

Dr. Denny's father, the original Mr. William Denny, was also engaged in shipbuilding. For three years, commencing in 1814, he was manager to Mr. James McLachlan, who had the first steam shipbuilding yard at Dumbarton, and subsequently for ten years he built on his own account. It was during this period that his son Peter was born, in the year 1821. At the age of twenty-two he, together with his elder brother William, the second shipbuilder of the name, established the famous firm of William Denny Brothers, at Dumbarton. They commenced business by building a Clyde passenger steamer named the *Loch Lomond*. In 1845 they built their first screw steamer, the *Water Witch*, of 240 tons and 30 N.H.P. In the year 1850 the brothers Denny, with Mr. Tulloch and Mr. McAusland, founded the firm of Messrs. Denny & Co., marine engine builders, at Dumbarton. In the early fifties they built several Cunard liners—vessels of about 1,400 tons. In 1861 Mr. Peter Denny carried on the works alone, his brother James having retired in that year. His brother William had died in 1854. At this period he built numerous vessels for the Cunard, the P. and O., and the British India companies, as well as for many of the other shipping companies of the time.

The year 1867 marked a new era in the history of the firm, for then the existing works were commenced, and in the following year Mr. Denny took, as his partner, his eldest son William, the third shipbuilder of the name, who, during his short life, was such an ornament to his profession, and such an active member of this Institution. The partnership between the subject of this memoir and his son worked admirably, not only in the interests of the firm, but for the advancement of the profession. The new works were excellently equipped, and were provided with every scientific apparatus of value. The part played by the firm in the introduction of steel for shipbuilding, in the adoption of cellular double bottoms for merchant ships, and in the advocacy of progressive speed trials, is well known, and is recorded in the Transactions of the Institution in the many interesting papers contributed by the late Mr. William Denny. Another subject in which the firm took a deep interest was the supplying of technical

information concerning the qualities of the ships built by them to the owners for the use of the captains.

The first steel ship built by the firm was the *Taeping*, launched in 1876, for the Irrawaddy Flotilla Company. This was a light-draught paddle steamer, and was constructed of Bessemer steel. Shortly afterwards they built another steamer for the same company, of mild Siemens steel, and in 1879 they built the first ocean-going steamer of mild steel, the *Rotomahana*, for the Union Steamship Company of New Zealand. The *Chilka* and the *Chupra*, built for the British India Steam Navigation Company, were the first vessels built by the firm with cellular double bottoms fitted to carry water ballast.

Mr. Denny's talents and business aptitude were by no means confined exclusively to the management of the two great establishments at Dumbarton. He took an active part in the conduct of several other important enterprises, such as the Irrawaddy Flotilla Company, the British India Company, the Union Steamship Company of New Zealand, the Shaw, Savill & Albion Company, and Patrick Henderson & Co. He was also a Member of the Royal Commission on the causes of the loss of life and of property at sea, and of the Parliamentary Committee presided over by Lord Dufferin on designs of ships of war. In 1890 he received the honorary degree of LL.D. from the University of Glasgow, and in the following year he was elected President of the Institute of Marine Engineers. He was the recipient of many foreign orders of merit, and was also a Fellow of the Royal Society of Edinburgh.

Dr. Denny was an original Associate of this Institution. He was elected a Member in the year 1868 and a Member of Council in 1876. In the year 1881 he was appointed a Vice-President, which office he retained till his death, which took place on August 22, 1895, in the seventy-fourth year of his age.

This notice would be incomplete without a reference to the kindness and generosity of Dr. Denny's disposition. He was a great benefactor to his native town, Dumbarton. In conjunction with the late Mr. John McMillan he presented to it a public park, and he was the active promoter of many schemes of improvement and erected both churches and schools. His great wealth and powers of organisation were at the disposal of innumerable charities and other worthy objects. He was a warm supporter of the Dumbarton Building Society, and he always encouraged and assisted his workpeople to become the proprietors of their own houses. Perhaps, the best testimony to the generosity of his character was the cordial relationship which existed between him and his numerous employés. He took the warmest interest in their social life, and in times of depression he came with an open hand to their assistance. On their side his workmen proved, on more than one occasion, that they were grateful for and thoroughly appreciated his kindness of heart. His loss is deeply deplored by his colleagues in the Institution, and by a large circle of friends and dependants.

Sir Edward Harland, Bart., M.P.

By the death of Sir Edward Harland, the Institution and the profession lose one of the greatest shipbuilders of the day. Though chiefly identified with the North of Ireland, Sir Edward Harland was an Englishman by birth, having been born in 1831 at Scarborough, where his father was a well-known physician.

Like many other eminent members of the profession, Sir Edward Harland was originally intended for another calling. It was his father's wish that he should become a lawyer; but the mechanical instinct was so strong in the son that eventually the father yielded, and, at the age of fifteen, young Harland was apprenticed to Messrs. Robert Stephenson & Co., at Newcastle-on-Tyne. After serving his time he remained in the employ of the firm as a journeyman artisan at twenty shillings a week wages.

In the year 1852, after visiting the Great Exhibition in London, he went to Glasgow, and was engaged as a journeyman by Messrs. Thomson, of Clyde Bank, who were at that time engine builders; but shortly afterwards the firm commenced shipbuilding, and young Harland very soon became chief ship's draughtsman. He did not, however, remain long with Messrs. Thomson; for, in 1853, he was appointed manager in the firm of Thomas Toward, on the Tyne.

In the following year he replied to an advertisement for a manager from Messrs. Robert Hickson & Co., of Queen's Island, Belfast, and obtained the post, but the firm got into difficulties and had to make an arrangement with its creditors. Business was recommenced, and, shortly afterwards, with the assistance of Mr. Schwabe, of Liverpool, Mr. Harland bought the works, and soon afterwards took into partnership Mr. Wolff, a nephew of Mr. Schwabe, who had served his apprenticeship as an engineer with Messrs. Joseph Whitworth & Co., of Manchester. Thus was founded the famous firm of Harland & Wolff.

Amongst the earliest orders received by the new firm was one for three iron screw steamers, from Messrs. J. Bibby, of Liverpool. These vessels were 270 ft. long, by 34 ft. beam. In 1862, when Messrs. Bibby placed a further order with the firm, Mr. Harland proposed that the new vessels should have a greater length, both absolutely, and relatively to their beam, and the *Grecian* and *Italian* were built of the same beam as the former trio, but 310 ft. long. Longitudinal strength was obtained by making the upper decks of iron, a system then in its infancy, but which was originally introduced in the *Great Eastern*. In spite of many prognostications of failure these vessels turned out entirely successful, and three more were ordered of the same beam, but 20 ft. longer. Sir Edward Harland was always a strong advocate down to the end of his life of long ships. He had, however, to encounter a great deal of opposition to his ideas. These vessels were nick-named "Bibby's Coffins" by people who prophesied

that they would never return to port; but they did nothing to justify the prophets of evil. On the contrary they proved highly successful, and many further orders were placed with the firm by Messrs. Bibby, each new vessel showing an increase in length over its predecessor.

Perhaps the vessels with which the name of Messrs. Harland & Wolff is most identified are those of the Oceanic Steam Navigation, commonly called the White Star Line. When this company was founded by Messrs. Ismay and Imrie, of Liverpool, six new steamers were ordered from Messrs. Harland & Wolff. They were to be capable of carrying heavy cargo as well as a full complement of passengers, between Liverpool and New York. The first of these vessels, named the *Oceanic*, was launched in August, 1870, and marked a new departure in the history of Transatlantic navigation. Every new improvement that could contribute either to the efficiency of the vessel or to the comfort of the passengers was embodied in her. She was 400 ft. long on keel, by 41 ft. wide, of 3,807 tons gross, and 2,000 I.H.P. She was the first Transatlantic liner fitted with vertical tandem compound engines. This was in the days of the infancy of the compound marine engine. The first-class passenger accommodation was placed amidships, and the saloon extended to the whole width of the ship. Over the saloon was a commodious promenade deck; gas, for lighting purposes, was manufactured on board, and electric bells fitted for the first time on board a passenger steamer. As is well known this vessel proved a very great success. She was followed by the *Britannic* and *Germanic*, which were celebrated ships in their day, and these were succeeded by a number of other steamers for the same line, each being an improvement on its predecessor, till the culminating point was reached in the *Majestic* and *Teutonic*, launched in 1889, and still the largest passenger steamers in the world, being 582 ft. long, by 57 ft. 8 in. beam, of 10,000 tons gross, and 18,000 I.H.P., developed in two sets of triple-expansion engines.

The White Star Line and Messrs. Harland & Wolff were not famous for great passenger steamers alone. Reference should also be made to their splendid cargo and live stock steamers. Amongst these may be mentioned the *Nomadic*, *Tauric*, and *Bovic*, built in 1891 and 1892, the *Gothic*, built for the New Zealand trade in 1893, and the *Civic* and *Georgic* also for the New Zealand trade, which are at present the largest cargo steamers afloat, being of over 10,000 tons gross measurement.

Messrs. Harland & Wolff also worked largely for many other shipowning firms; they built many fine sailing ships for Messrs. J. P. Corry & Co. In 1893 and 1894 they headed the list for tonnage built. In 1895 they were second on the list, and now they are building, amongst many other vessels, the *Pennsylvania*, which will be the largest cargo steamer in the world. The firm commenced engine-building in 1880, and in 1884 constructed as much as 41,800 I.H.P. The works, which occupied two acres when taken over by Mr. Harland, covered at the time of his death an area of eighty acres.

Sir Edward Harland was Mayor of Belfast during the visit of the Prince and Princess of Wales to Ireland, in the year 1885, was re-elected in 1885-86, and represented the North Division of the City in Parliament continuously since the year 1889. He was High Sheriff of co. Down in 1887, and was created a baronet in the year 1885. For several years previously he had been Chairman of the Belfast Harbour Board.

Though he never read a paper before this Institution, Sir Edward Harland frequently took part in the discussions at the meetings. He was elected a member of the Institution in 1867, and a member of the Council in 1876. He died at Glenfarne Hall, in the County Leitrim, on the 23rd of December last, at the comparatively early age of sixty-four years.

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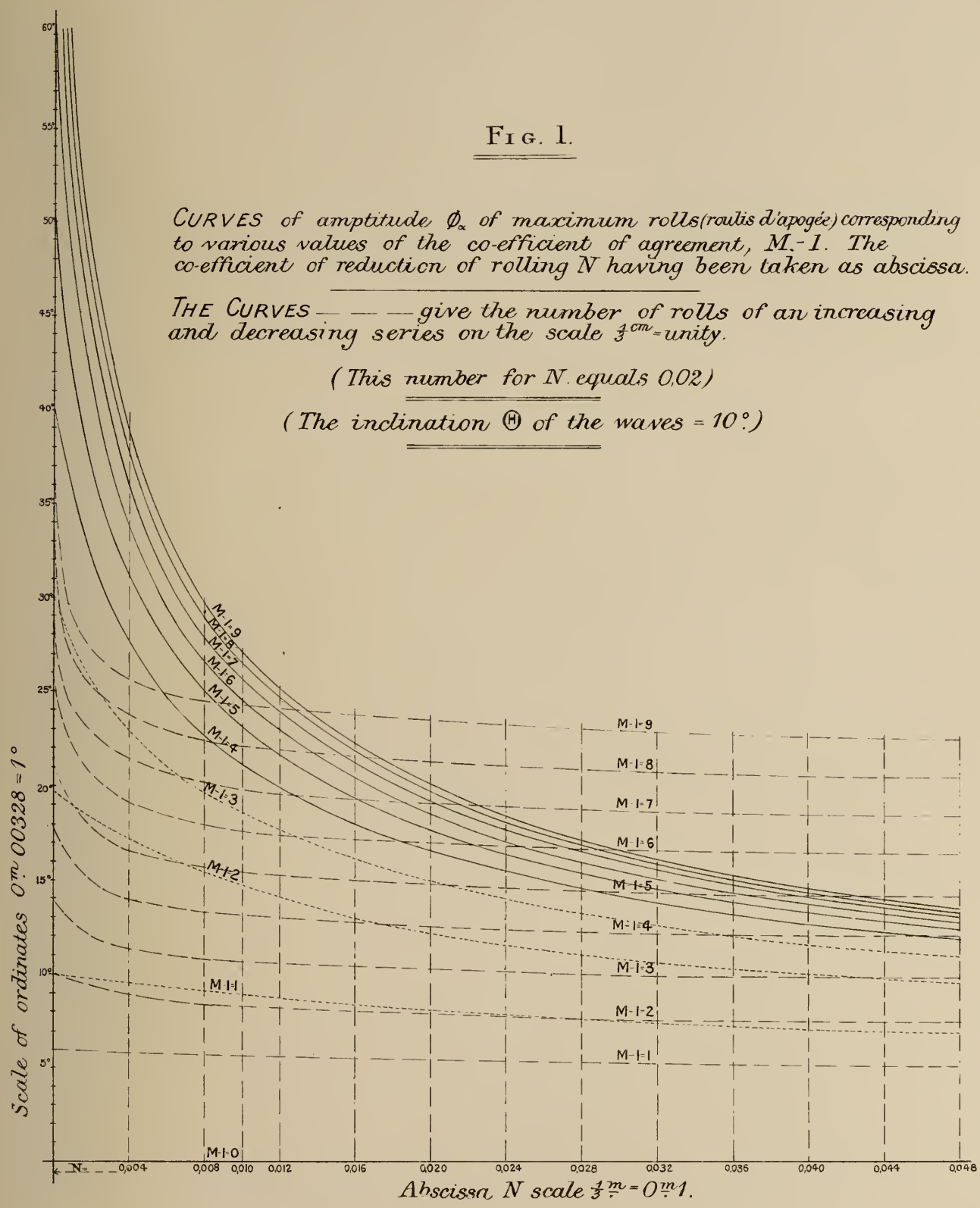

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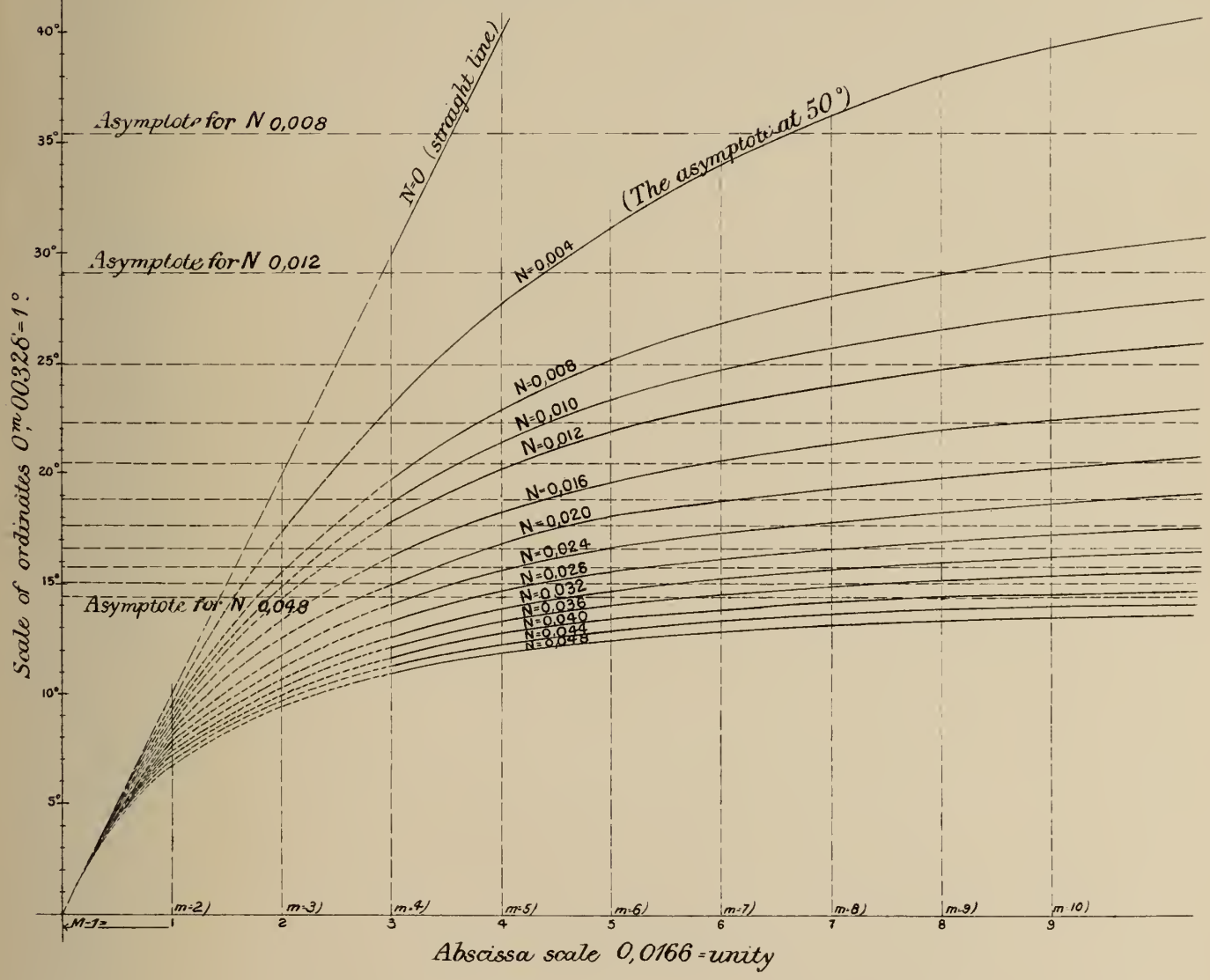
FIG. 2.

CURVES of the amptitudes Φ_α of maximum rolls (roulis d'apogée) corresponding to various values of the co-efficient of decrease N, the co-efficients of agreement M-I having been taken for abscissa.

(The inclination Θ of the waves = 10°)



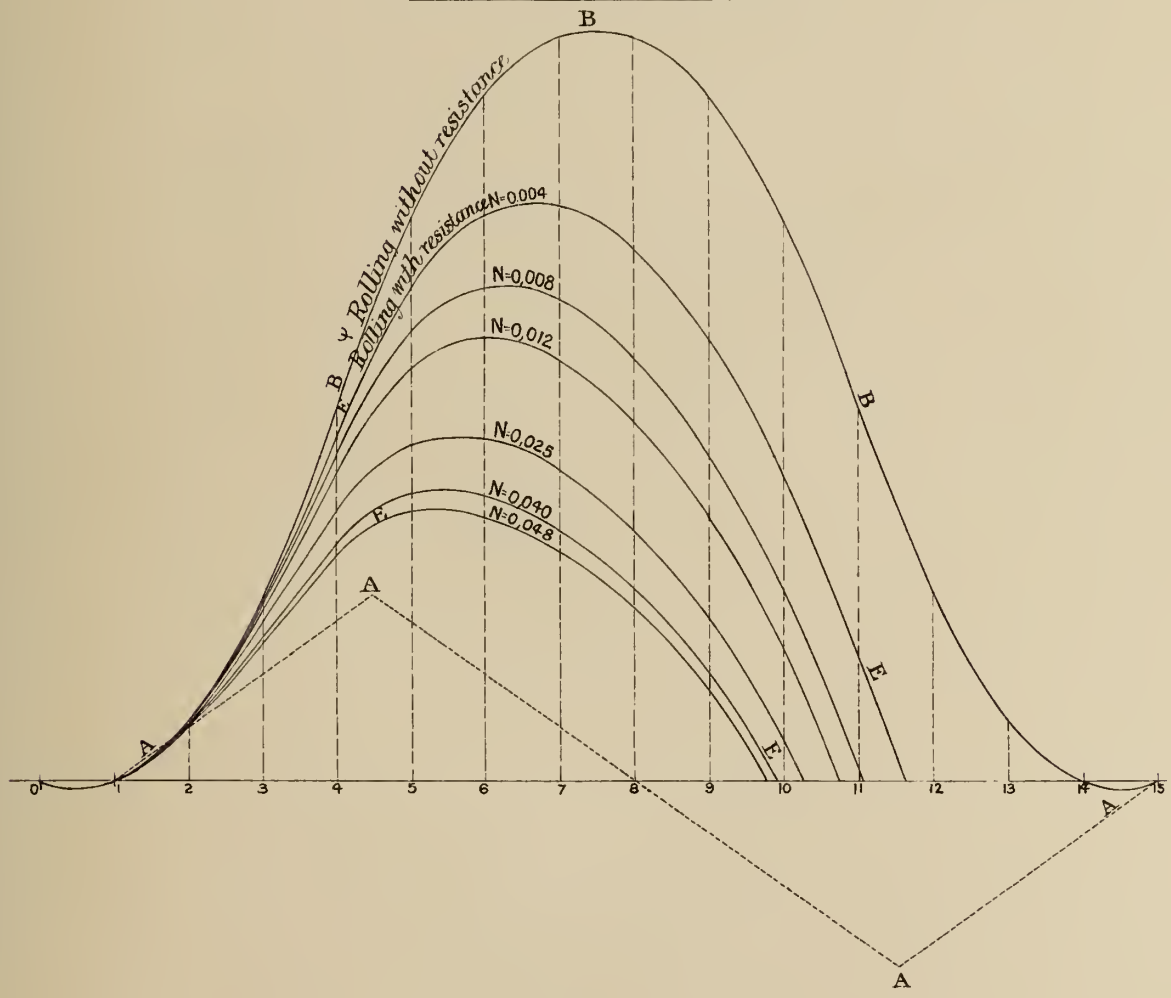
To Illustrate Monsieur Emil Bertin's Paper on the Amplitude of Rolling on a non-synchronous Wave

FIG. 3.

CURVES of a series of rolls corresponding with different values of N.

M-1-3

Scale of ordinates, 0,m 0,00325=1°.



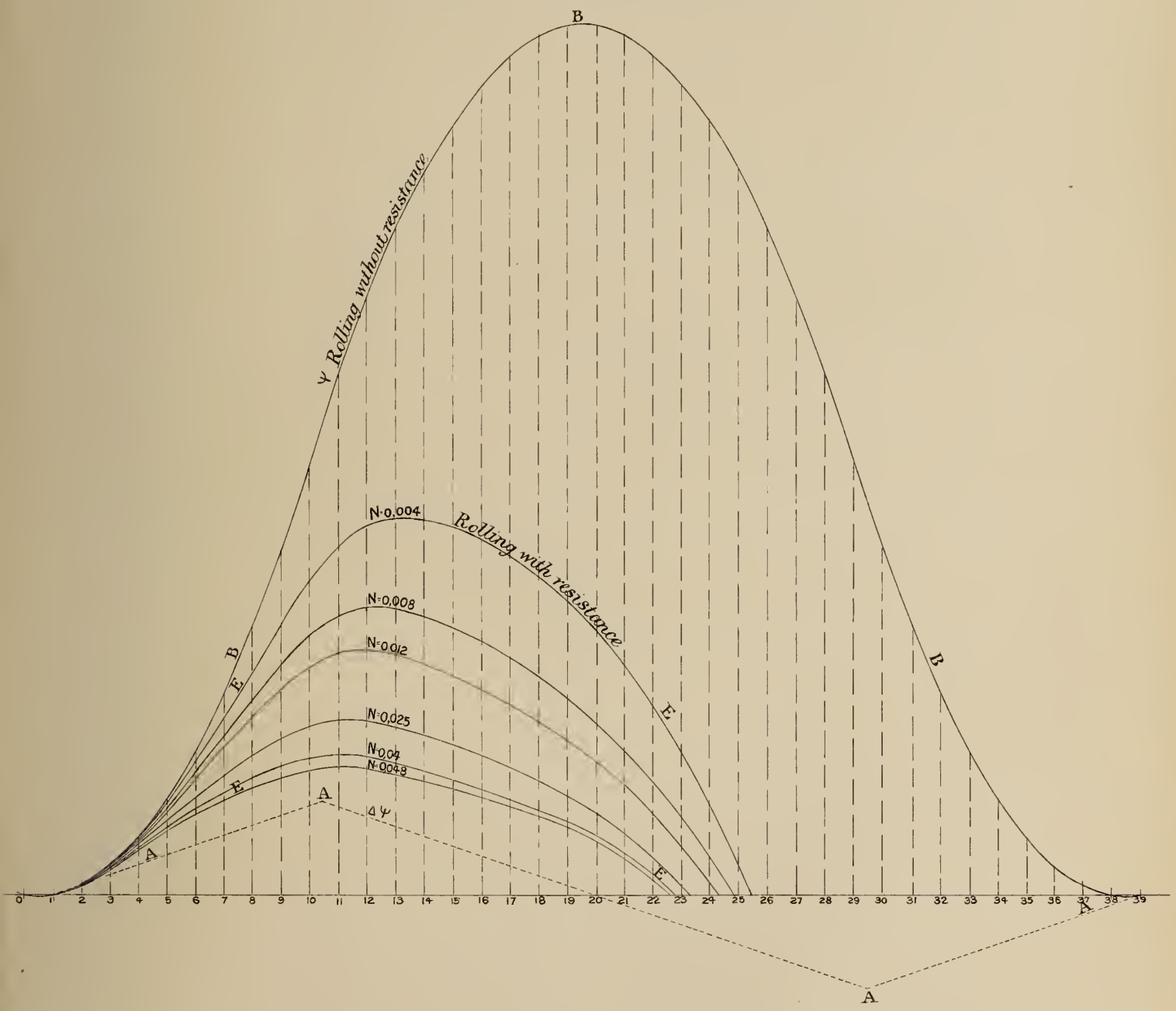
To Illustrate Monsieur Emil Bertin's Paper on the Amplitude of Rolling on a non-synchronous Wave.

FIG. 3A.

CURVES of a series of Rolls corresponding to various values of N.

M-1 = 9.

Scale of Ordinates 0,m00166 = 1°



To Illustrate Monsieur Emil Bertin's Paper on the Amplitude of Rolling on a non-synchronous Wave.

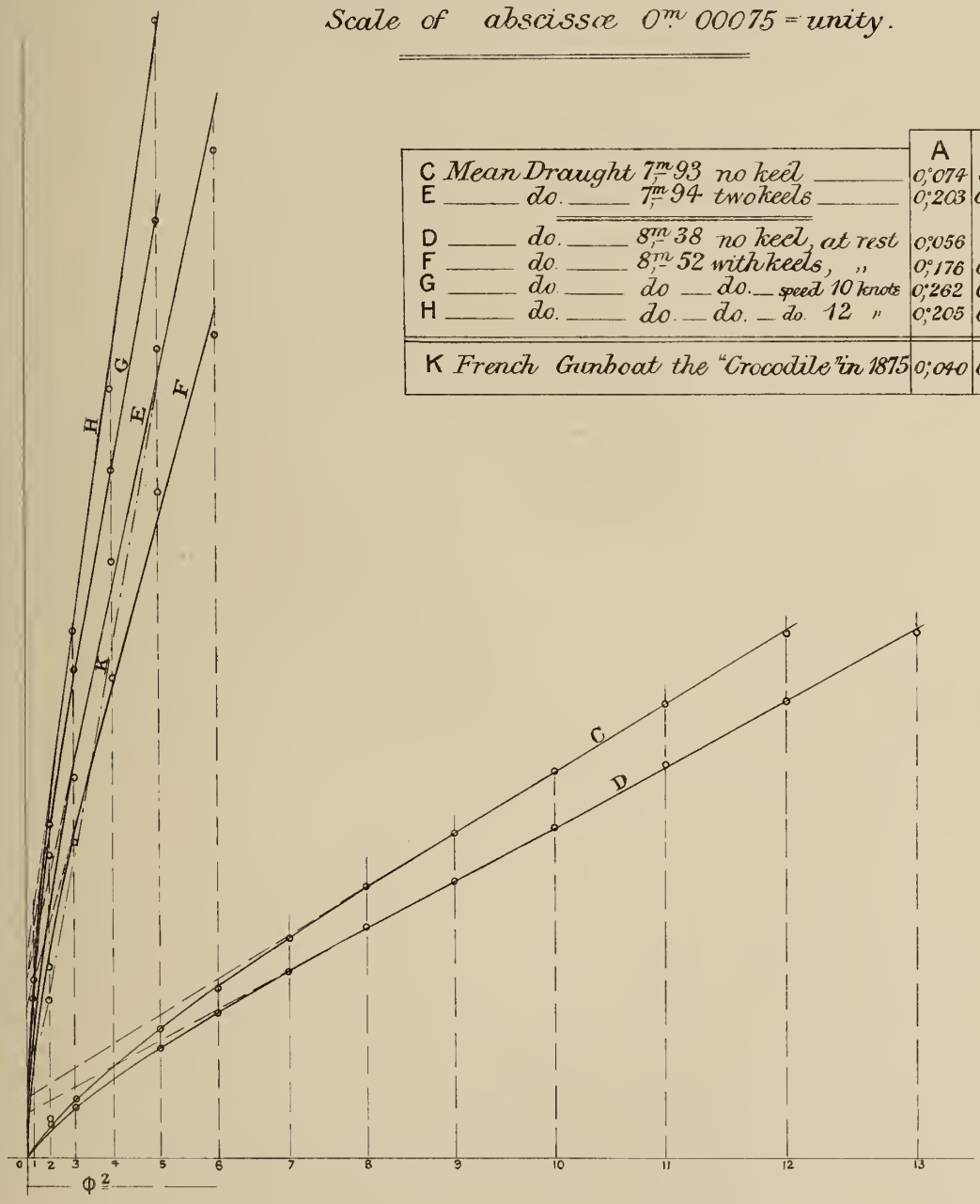
FIG. 4.

Declining Angle Curves of the Rolling of H.M.S. "REVENGE" in smooth water.

Scale of ordinates $0^{m}.125 = 1°$

Scale of abscissæ $0^{m}.00075$ = unity.

		A	N
C	Mean Draught $7^{m}.93$ no keel	0°.074	0,0036
E	do. $7^{m}.94$ two keels	0°.203	0,0276
D	do. $8^{m}.38$ no keel, at rest	0°.056	0,0032
F	do. $8^{m}.52$ with keels, "	0°.176	0,0221
G	do. do. do. speed 10 knots	0°.262	0,0322
H	do. do. do. do. 12 "	0°.205	0,0429
K	French Gunboat the "Crocodile" in 1875	0°.040	0,033



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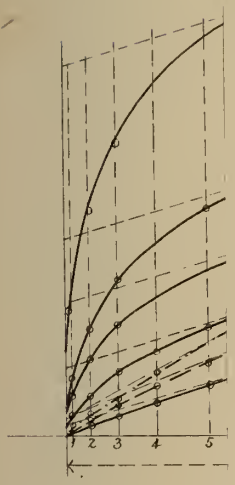


To Illustrate Monsieur Emil Bertin's Paper on the Amplitude of Rolling on a non-synchronous Wave.

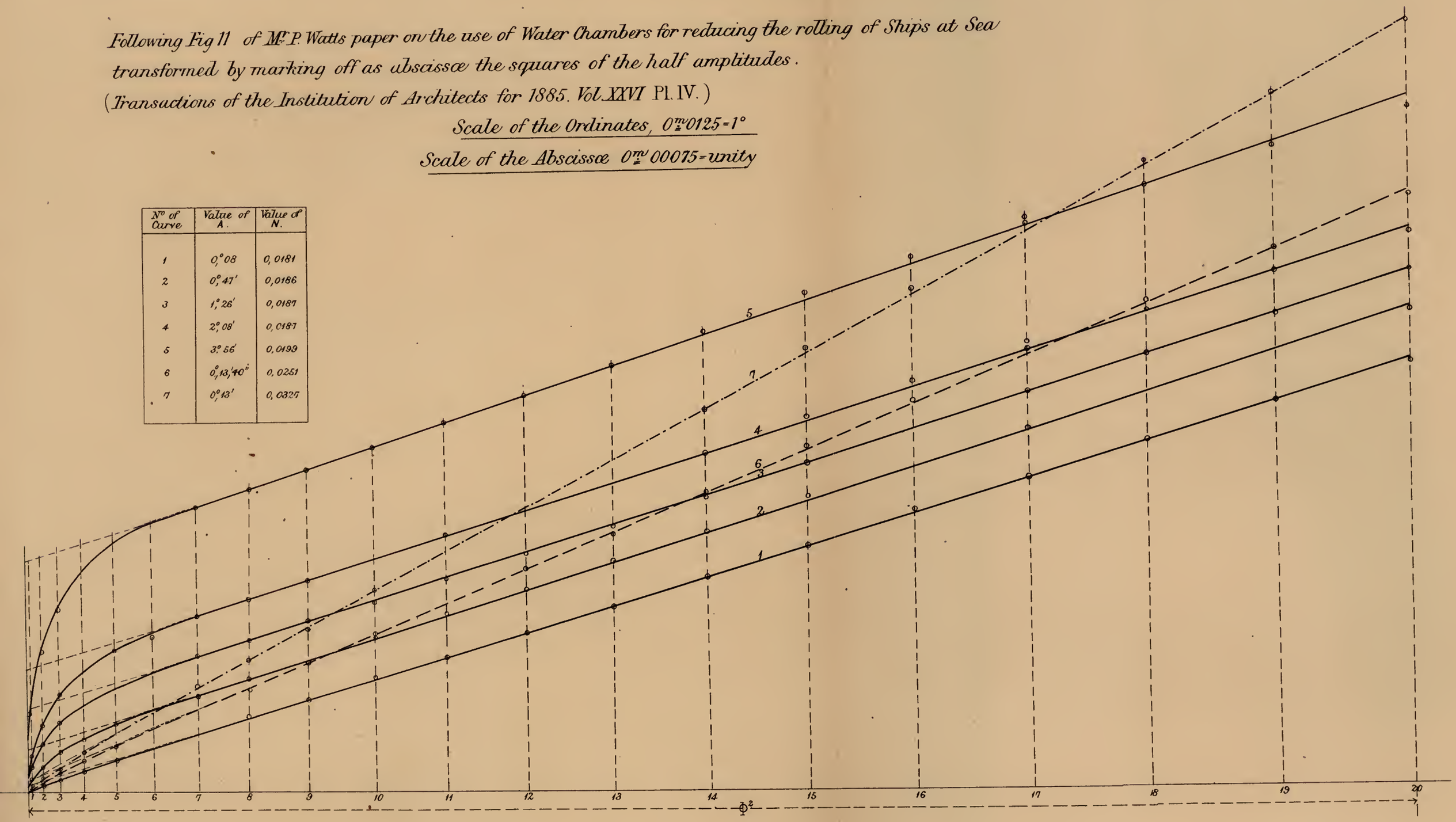
DECLINING ANGLE CURVES OF THE ROLLING OF H. M. S. EDINBURGH.

Following Fig 11 of Mr P. Watts paper on the use of Water Chambers for reducing the rolling of Ships at Sea transformed by marking off as abscissæ the squares of the half amplitudes.
(Transactions of the Institution of Architects for 1885. Vol. XXVI Pl. IV.)

Scale of the Ordinates, 0m0125 = 1°

Scale of the Abscissæ 0m00075 = unity

N° of Curve	Value of A.	Value of N.
1	0,°08	0,0181
2	0°,47'	0,0186
3	1°,26'	0,0187
4	2°,08'	0,0187
5	3°,56'	0,0199
6	0°,13',40"	0,0251
7	0°,13'	0,0327

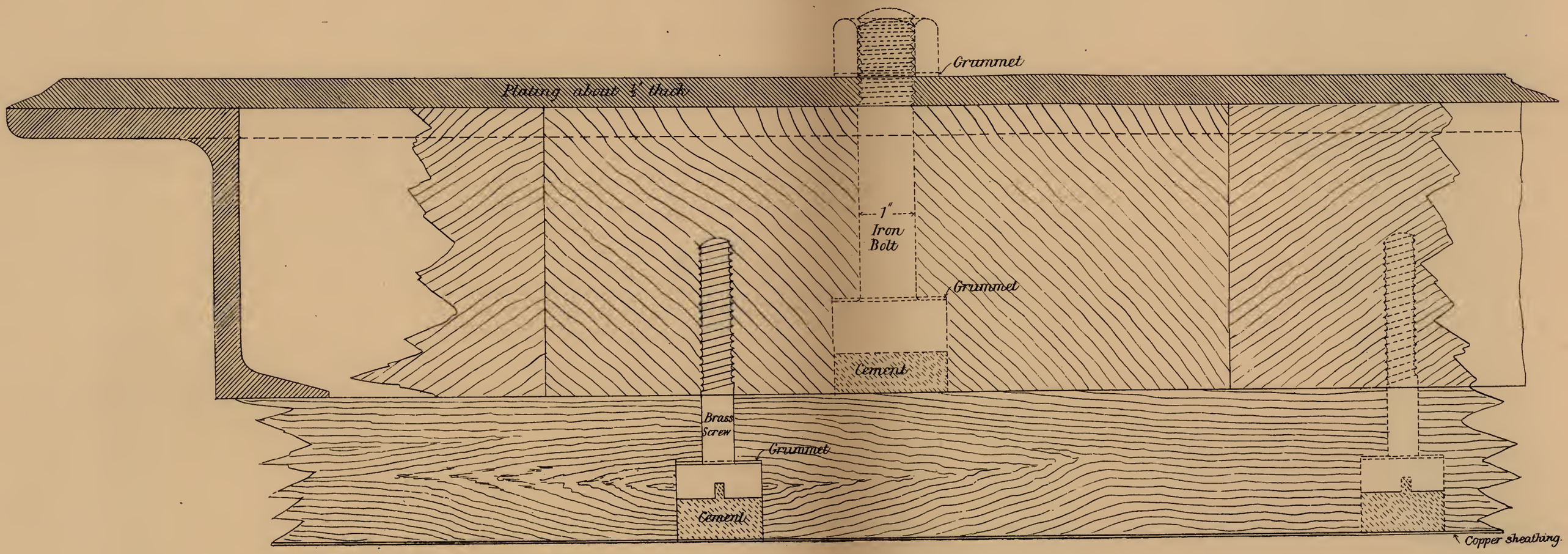


To Illustrate Sir William H. White's Paper on Wood and Copper Sheathing for Steel Ships.

FIG. 2.

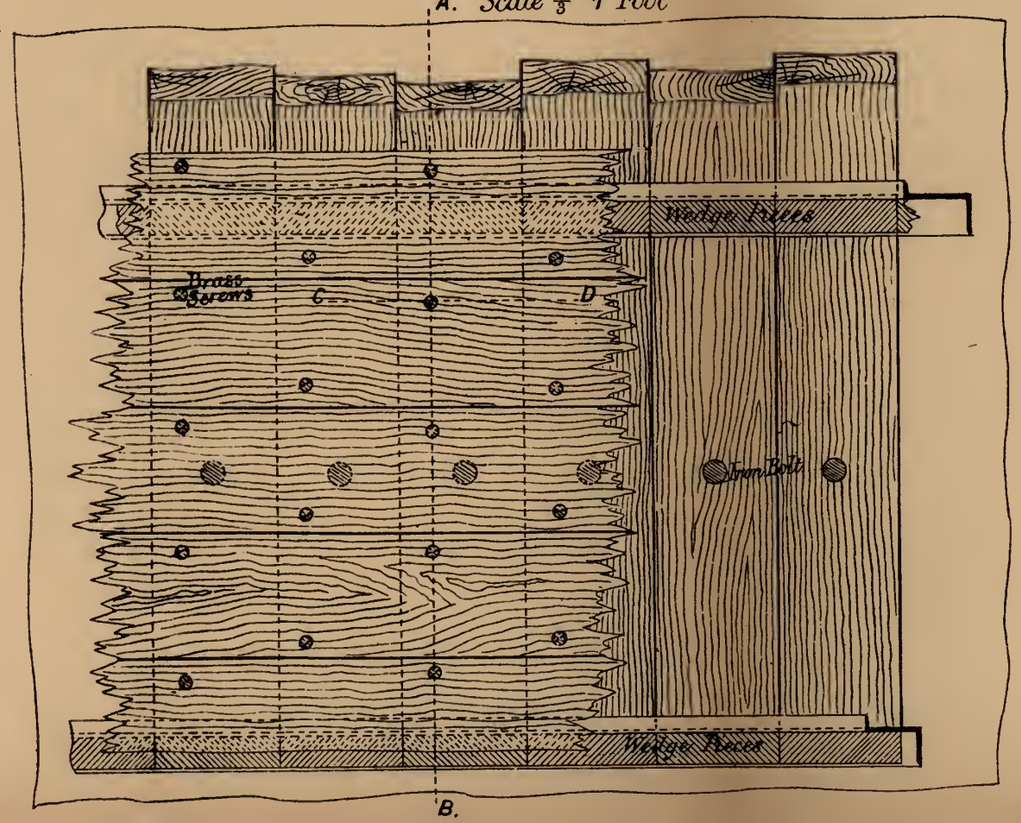
HORIZONTAL SECTION THROUGH C. D. IN FIG. 1.

Scale half Full Size.



ELEVATION.

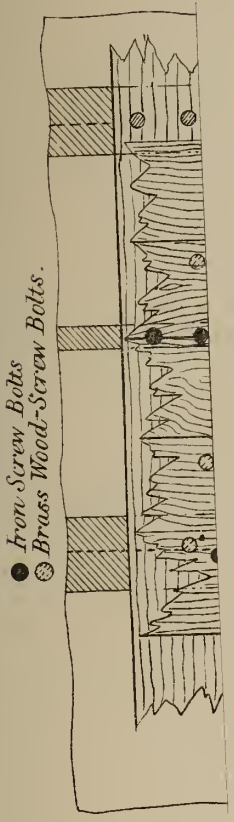
A. Scale ⅔" 1 Foot



VERTICAL SECTION THROUGH A.B.

Scale ⅔" - 1 Foot

FIG. 1.


Iron Screw Bolts
Brass Wood-Screw Bolts.

To Illustrate Sir William H. White's Paper on Wood and Copper Sheathing for Steel Ships.

FIG. 3.

ELEVATION OF SIDE.

Scale $\frac{2''}{3}$ – 1 Foot

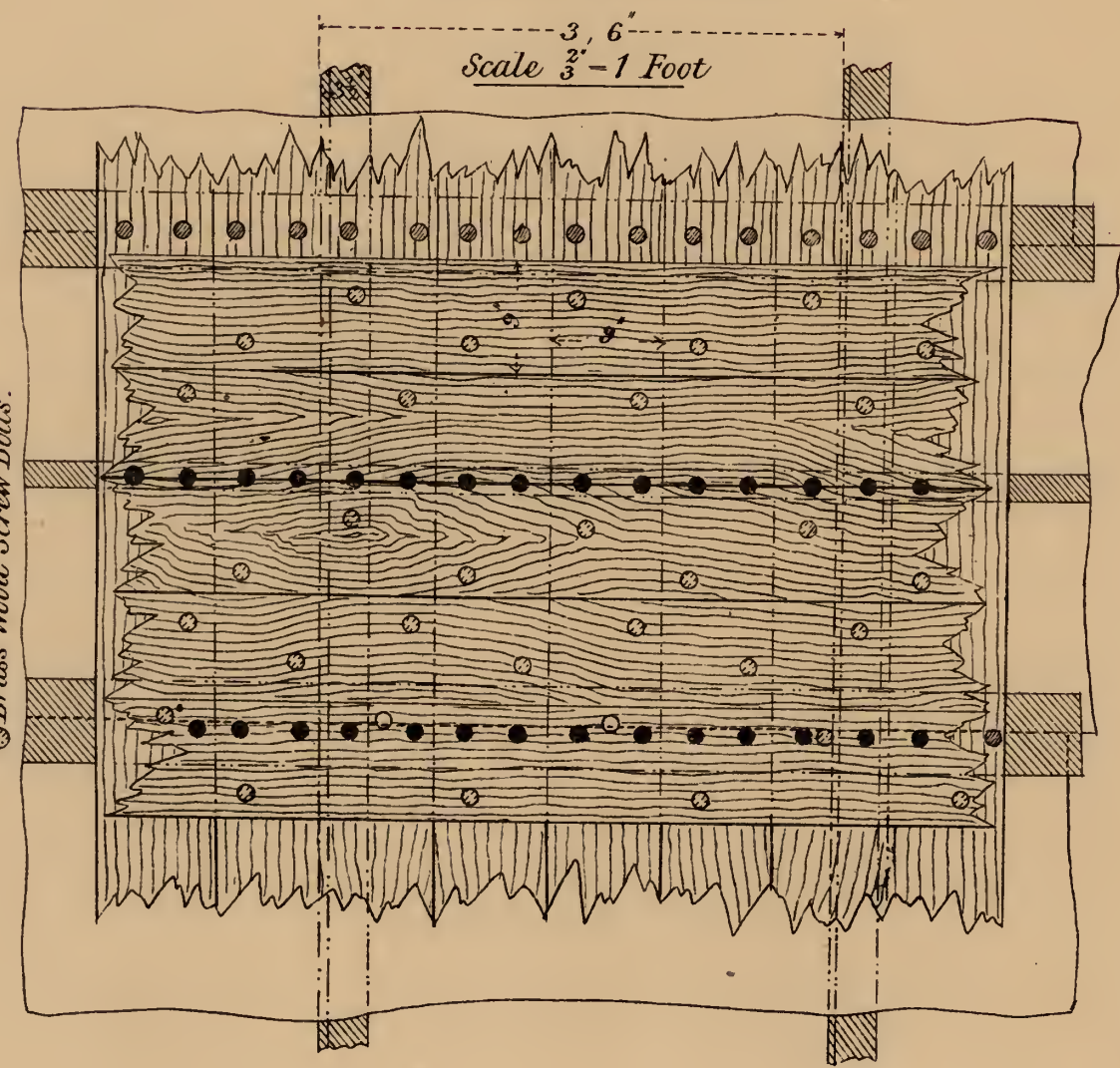
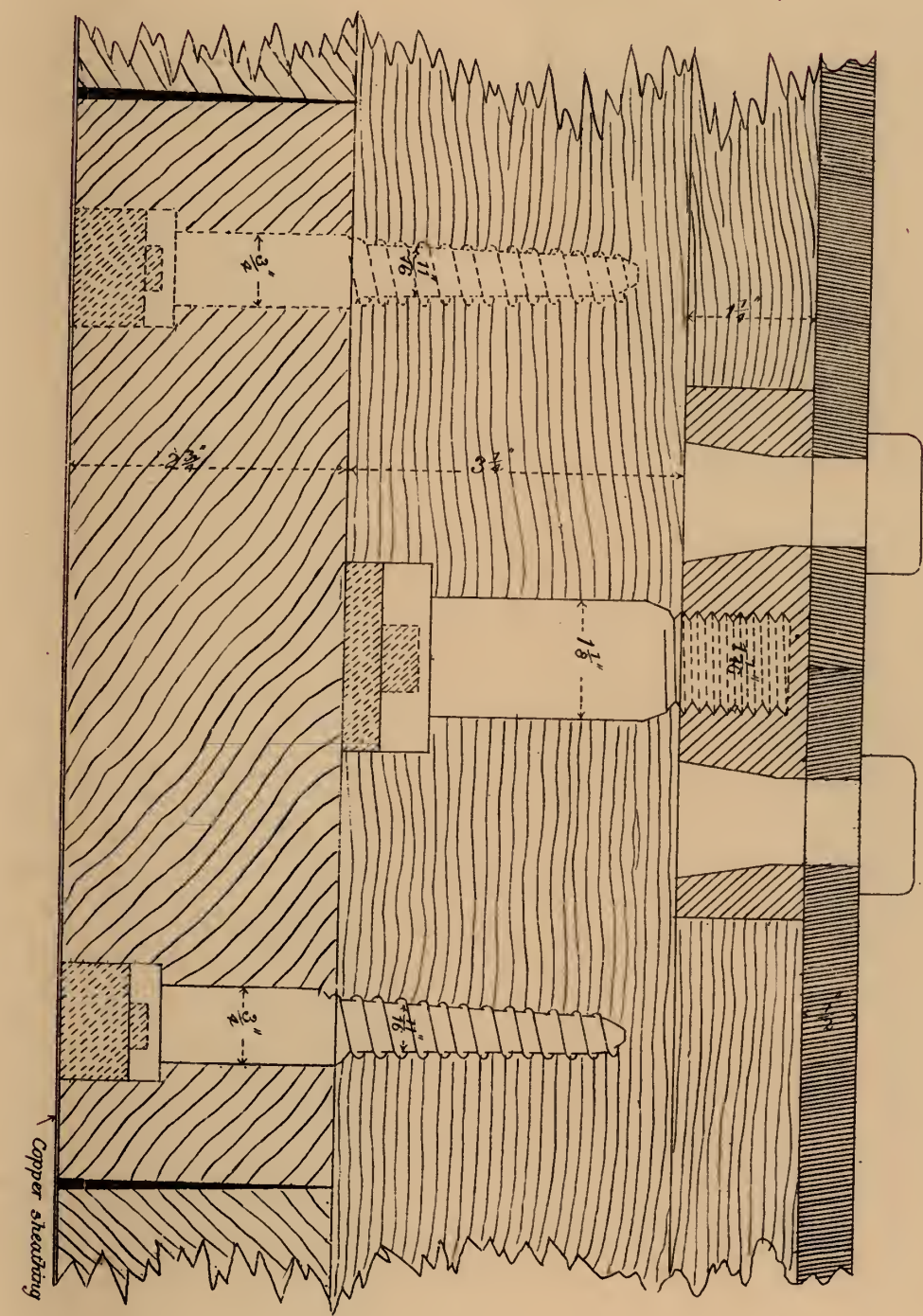


FIG. 4.

VERTICAL SECTION OF SIDE.

Scale half Full Size.

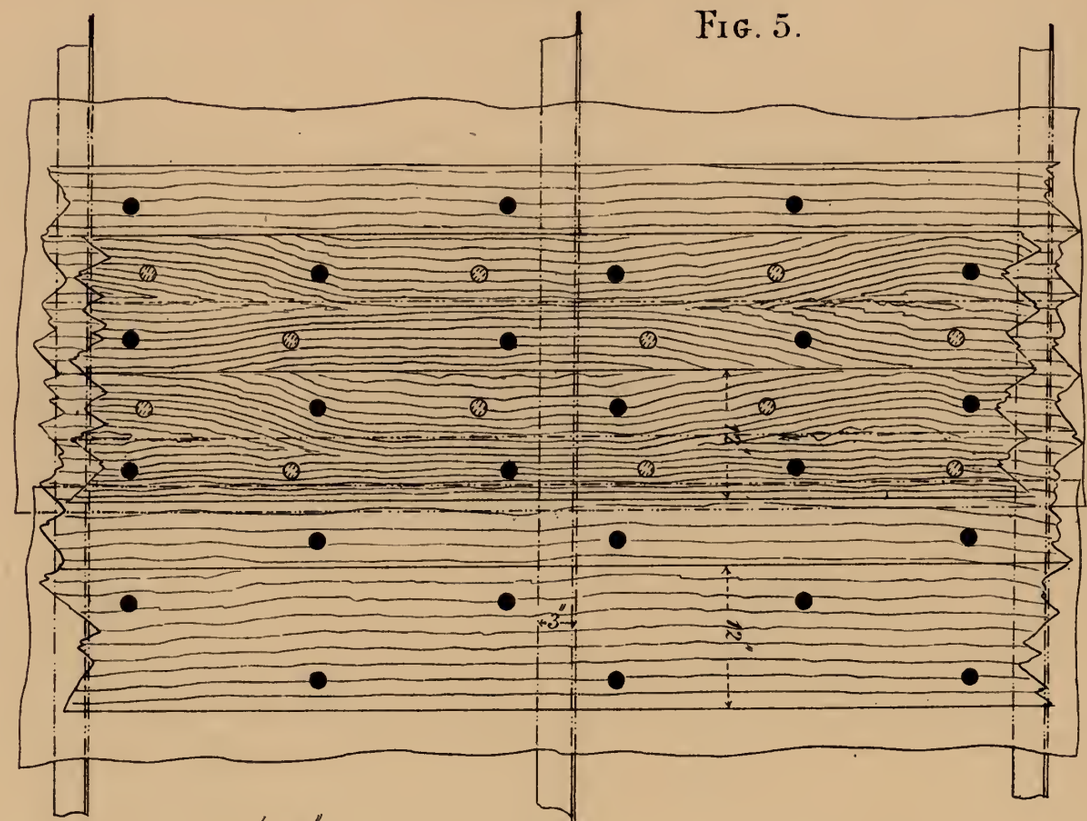


To Illustrate Sir William H. White's Paper on Wood and Copper Sheathing for Steel Ships.

ELEVATION OF SIDE.

Scale, $\frac{2}{3}$" = 1 Foot.

FIG. 5.

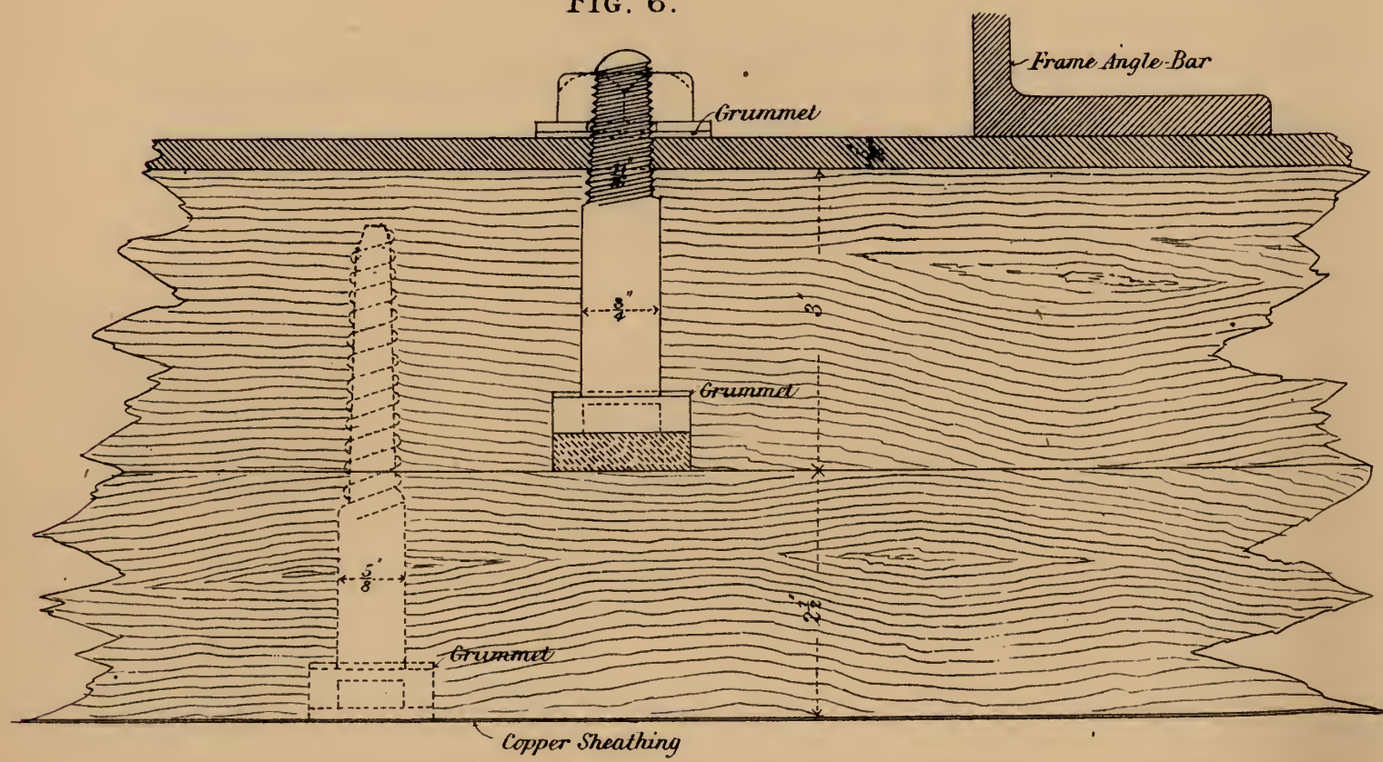


● Iron Nut and Screw Bolts
⊗ Brass, Wood-Screw Bolts.

HORIZONTAL SECTION OF SIDE.

Scale half Full Size.

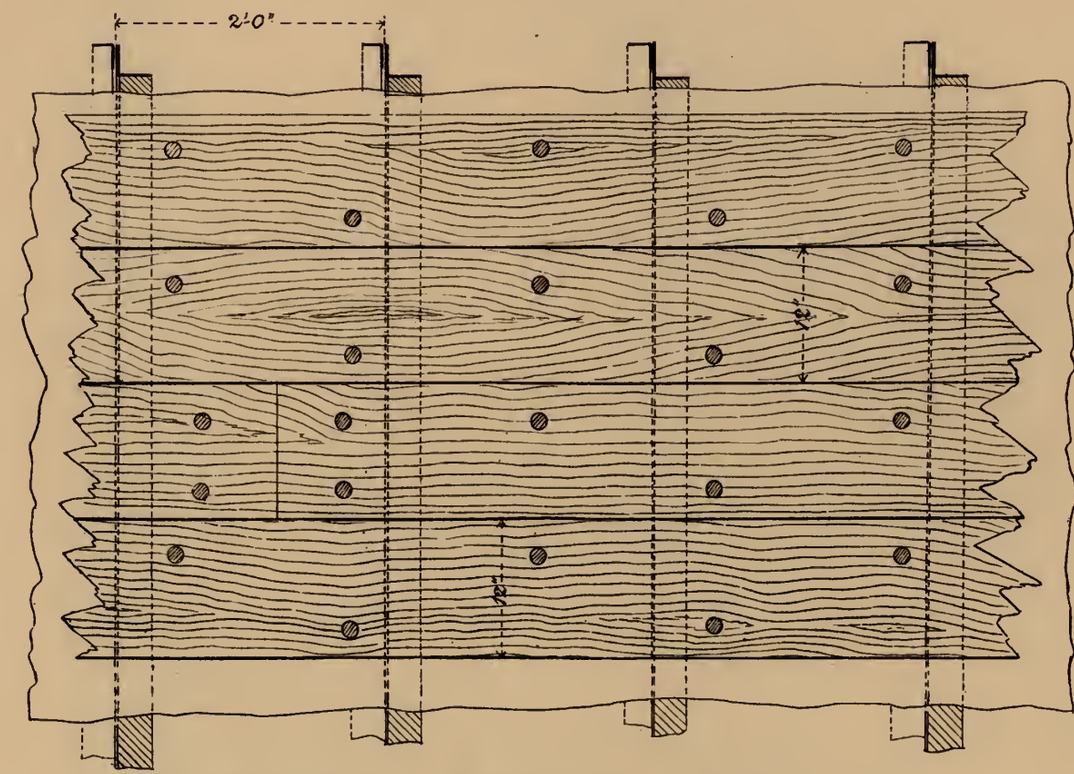
FIG. 6.



ELEVATION OF SIDE.

Scale, $\frac{2}{3}$" = 1 Foot.

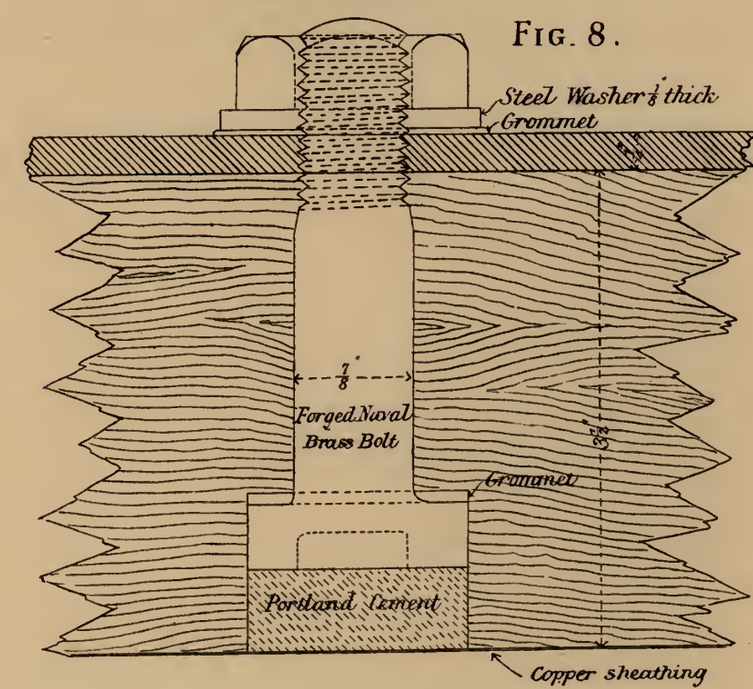
FIG. 7.



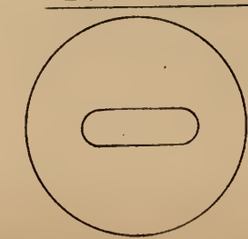
HORIZONTAL SECTION OF SIDE.

Scale, $\frac{2}{3}$rd Full Size.

FIG. 8.



Plan of Bolt Head



To Illustrate Mr. Archibald Denny's Paper on the M. G. Meter.

FIG. 1.

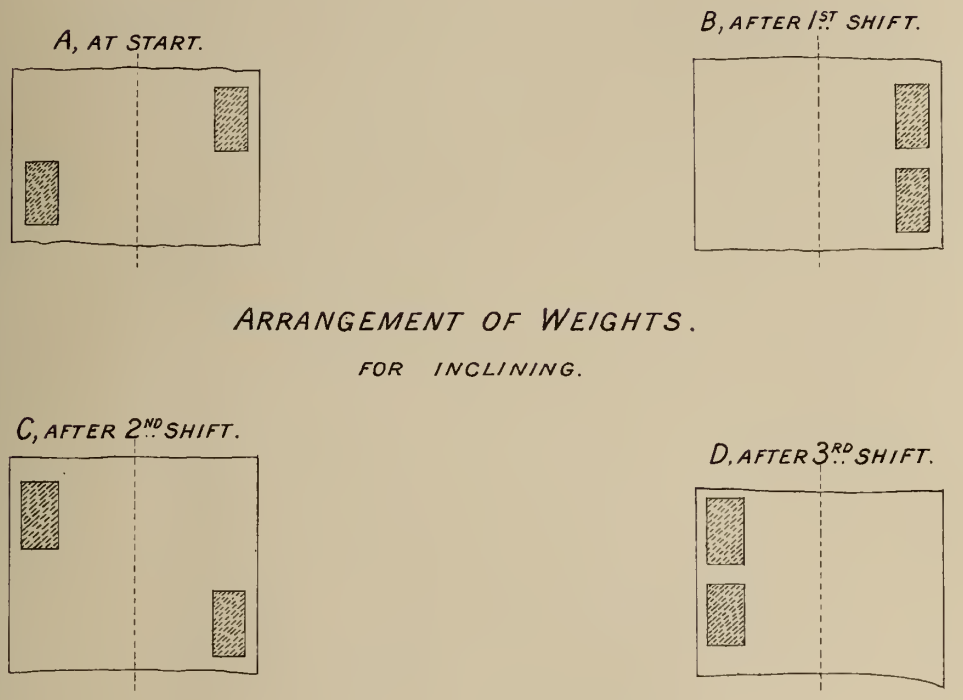


FIG. 2.

M. G. METER.
FOR
MEASURING THE METACENTRIC HEIGHT OF SHIPS.

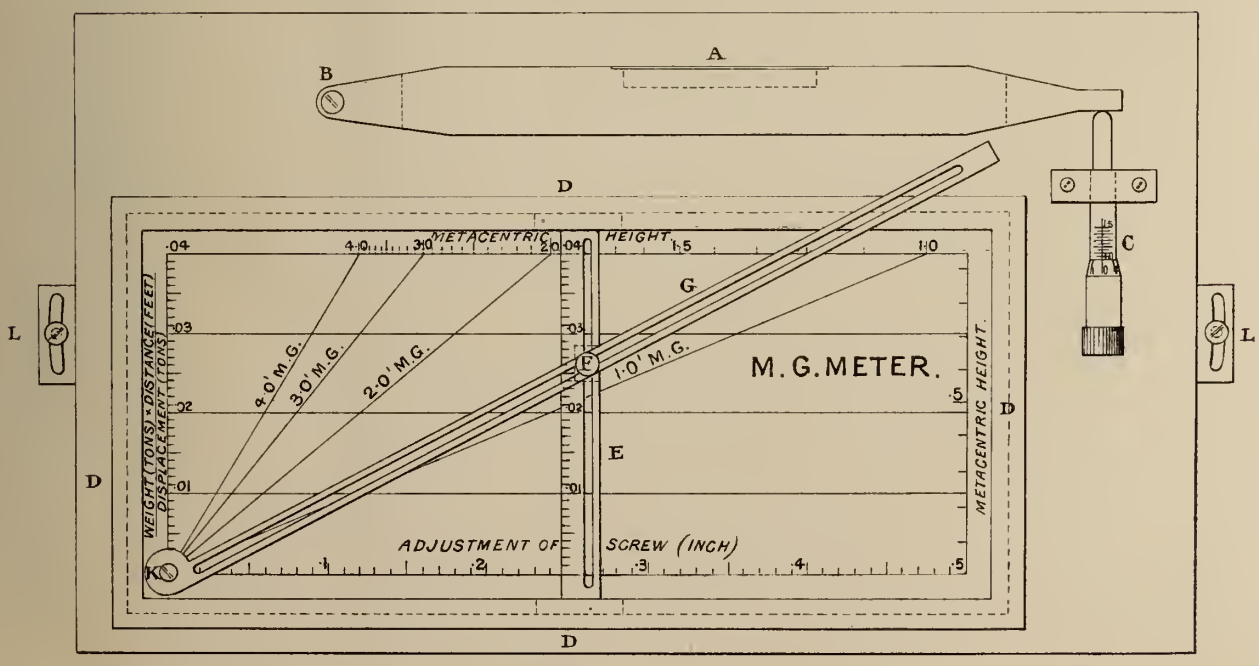


FIG. 1A

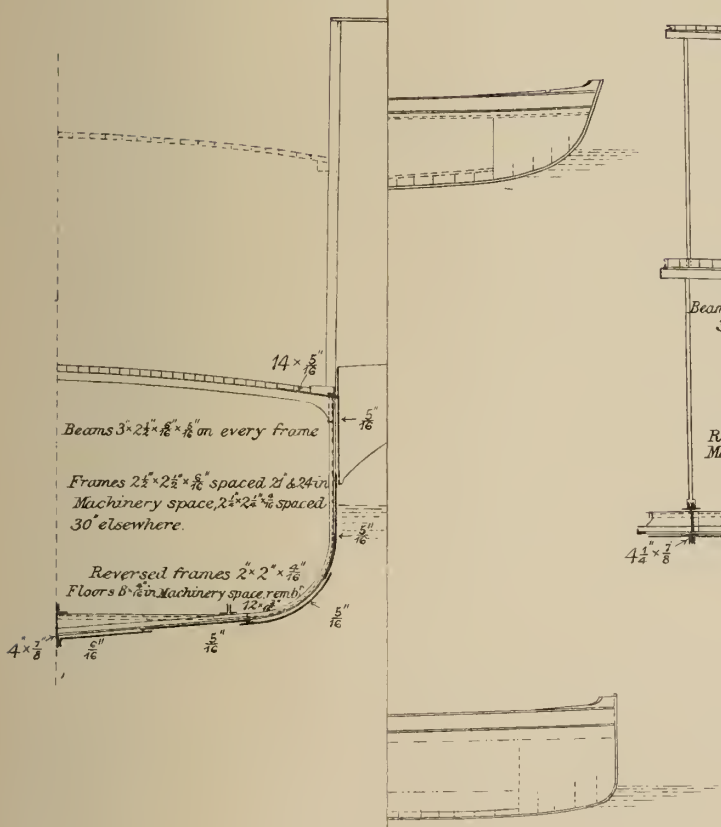
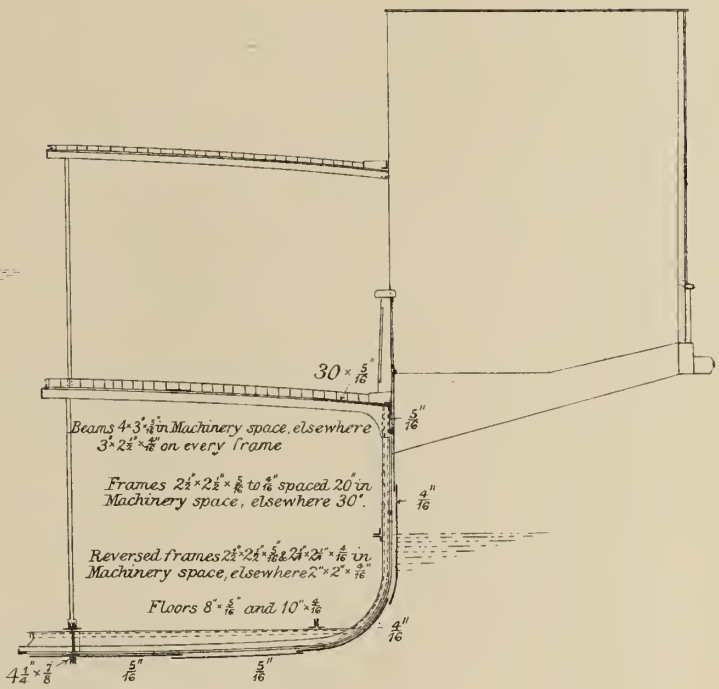

14 × 5/16"
Beams 3" × 2½" × 5/16" × 5/16" on every frame
Frames 2½" × 2½" × 5/16" spaced 21" & 24 in Machinery space, 2¼" × 2¼" × 4/16" spaced 30" elsewhere.
Reversed frames 2" × 2" × 4/16"
Floors 8" × 5/16" in Machinery space, remb.
12 × 3/8"
5/16"
5/16"
5/16"
5/16"
4" × 7/8"
6/16"
5/16"

FIG. 2A


30 × 5/16"
5/16"
Beams 4 × 3" × 3/16" in Machinery space, elsewhere 3" × 2½" × 4/16" on every frame
Frames 2½" × 2½" × 5/16" to 4/16" spaced 20" in Machinery space, elsewhere 30".
4/16"
Reversed frames 2½" × 2½" × 5/16" & 2¼" × 2¼" × 4/16" in Machinery space, elsewhere 2" × 2" × 4/16"
Floors 8" × 5/16" and 10" × 4/16"
4/16"
4¼" × 7/8"
5/16"
5/16"

To Illustrate Mr. B. Martell's Paper on light Scantling Steamers.

IRON PADDLE STEAMER FOR RIVER SERVICE ONLY.

Principal Dimensions.
Length..... 196·6 feet.
Breadth..... 18·1 „ .
Depth of Hold 7·3 „ .

Tonnage
Gross 196. Net 54.

FIG. 1A.

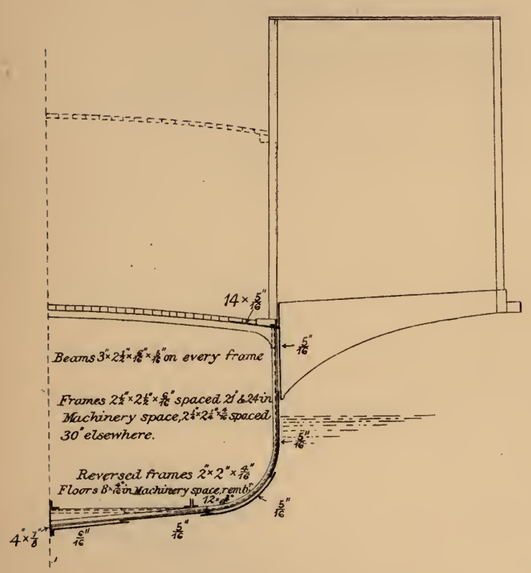
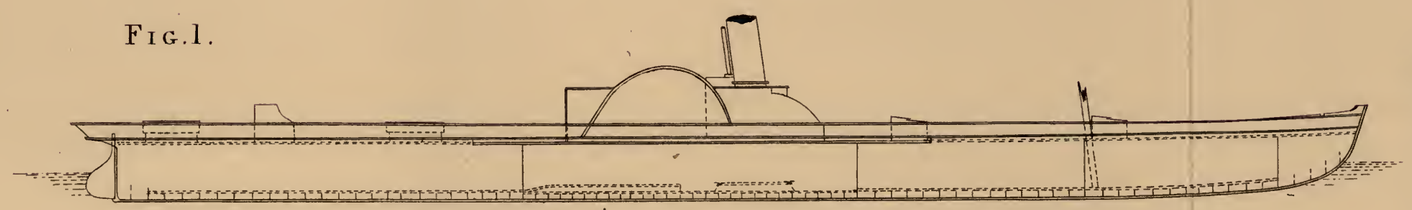


FIG. 1.



STEEL PADDLE STEAMER FOR RIVER SERVICE ONLY.

Principal Dimensions
Length..... 210·0 feet.
Breadth 20·1 „ .
Depth of Hold 7·6 „ .

Tonnage
Gross 268. Net 120.

FIG. 2.

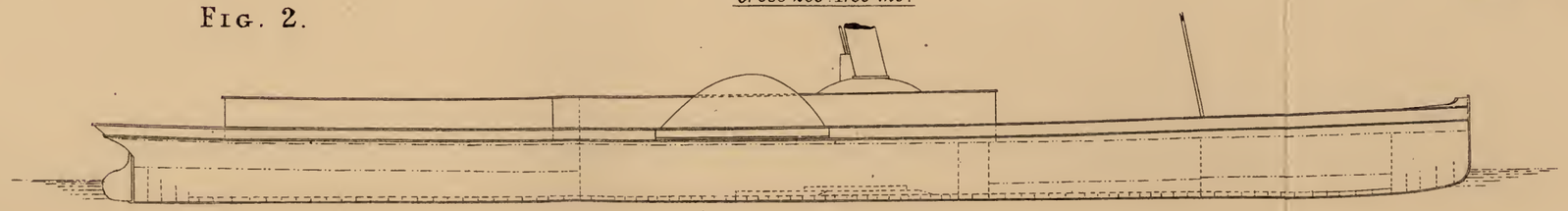


FIG. 2A.

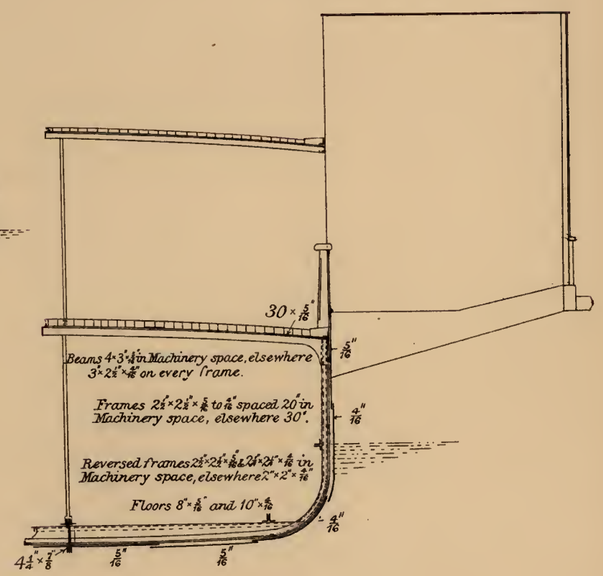
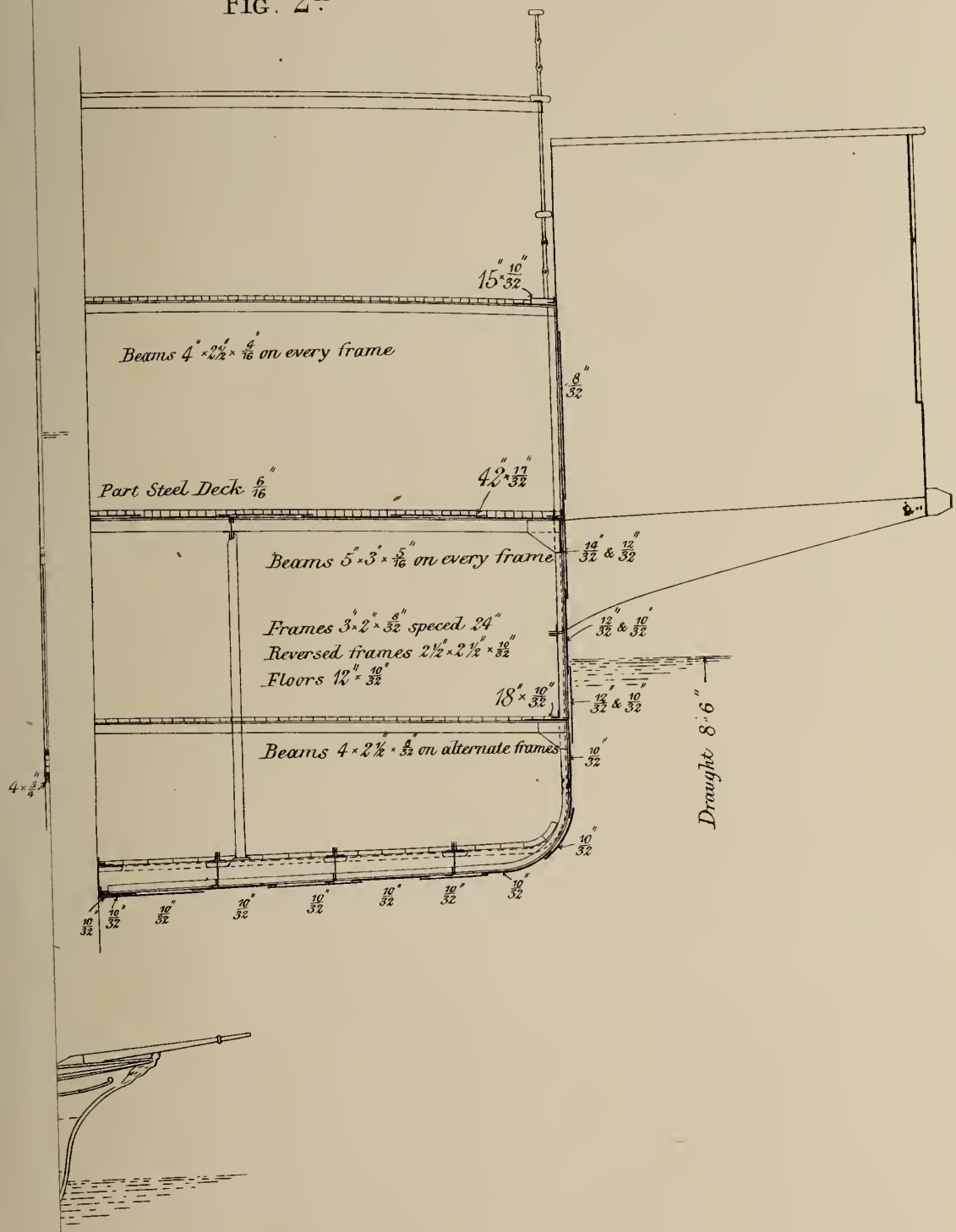


FIG. 2A.


15" × 10"/32
Beams 4" × 2½" × 4"/16 on every frame
8"/32
Part Steel Deck 6"/16
42" × 17"/32
Beams 5" × 3" × 5"/16 on every frame
14"/32 & 12"/32
Frames 3" × 2" × 8"/32 speced 24"
Reversed frames 2½" × 2½" × 10"/32
Floors 12" × 10"/32
12"/32 & 10"/32
18" × 10"/32
12"/32 & 10"/32
Beams 4 × 2½" × 8"/32 on alternate frames
10"/32
4 × 3"/4
Draught 8'6"
10"/32
10"/32
10"/32
10"/32
10"/32
10"/32
10"/32
10"/32
10"/32

To Illustrate Mr. B. Martell's Paper on light Scantling Steamers.

STEEL PADDLE STEAMER FOR RIVER SERVICE ONLY

Principal Dimensions
Length ..... 215.0 ft.
Breadth ..... 22.0 "
Depth of Hold ..... 7.5 "

Tonnage
Gross 276. Net 106.

FIG. 1A.

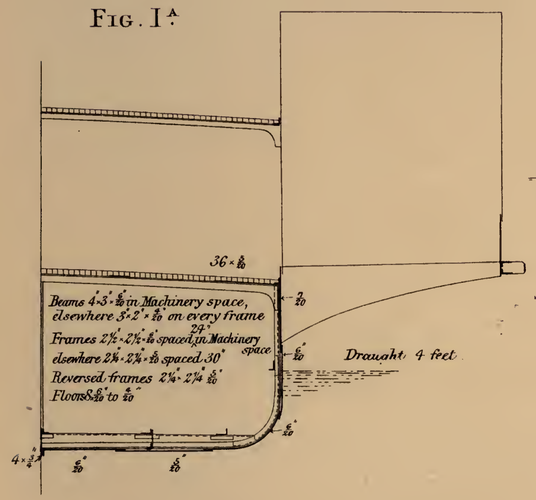
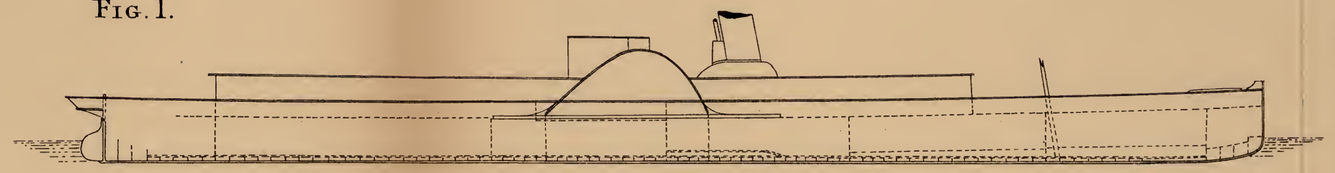


FIG. 1.



STEEL PADDLE STEAMER FOR RIVER SERVICE

Principal Dimensions
Length ..... 239.0 ft.
Breadth ..... 35.1 "
Depth of Hold ..... 12.8 "

Tonnage
Gross 1749. Net 969

FIG. 2.

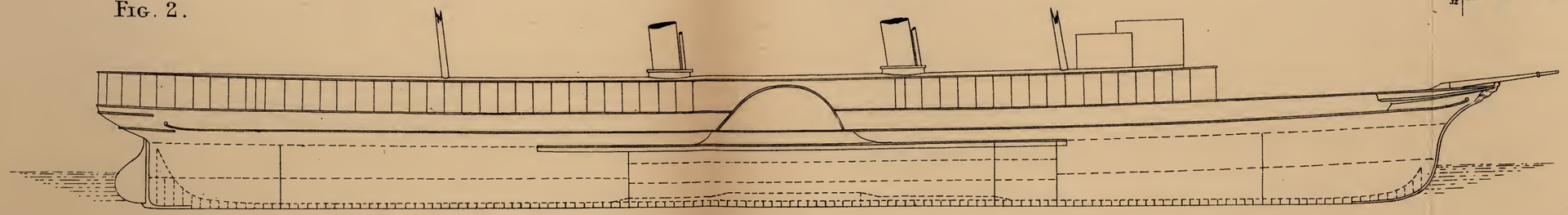


FIG. 2A.

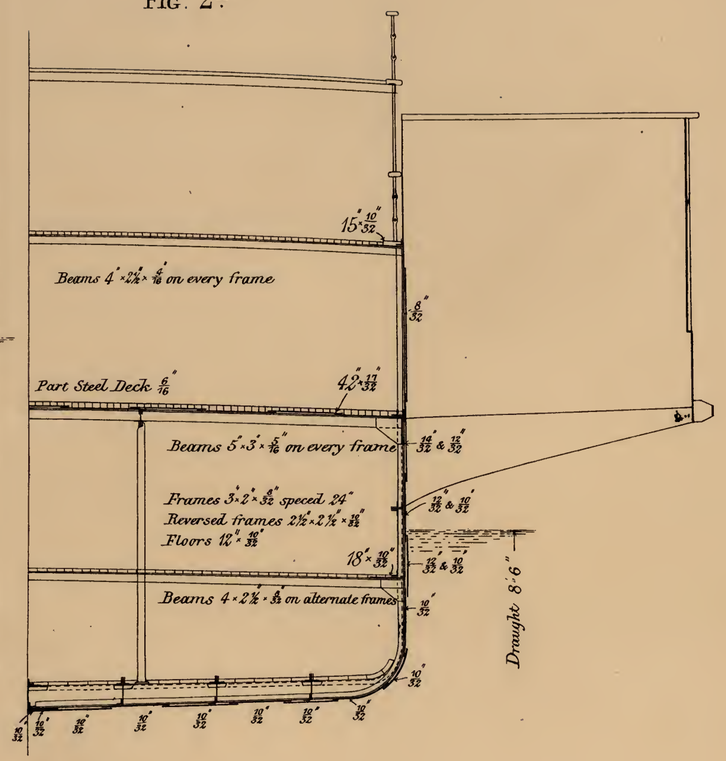
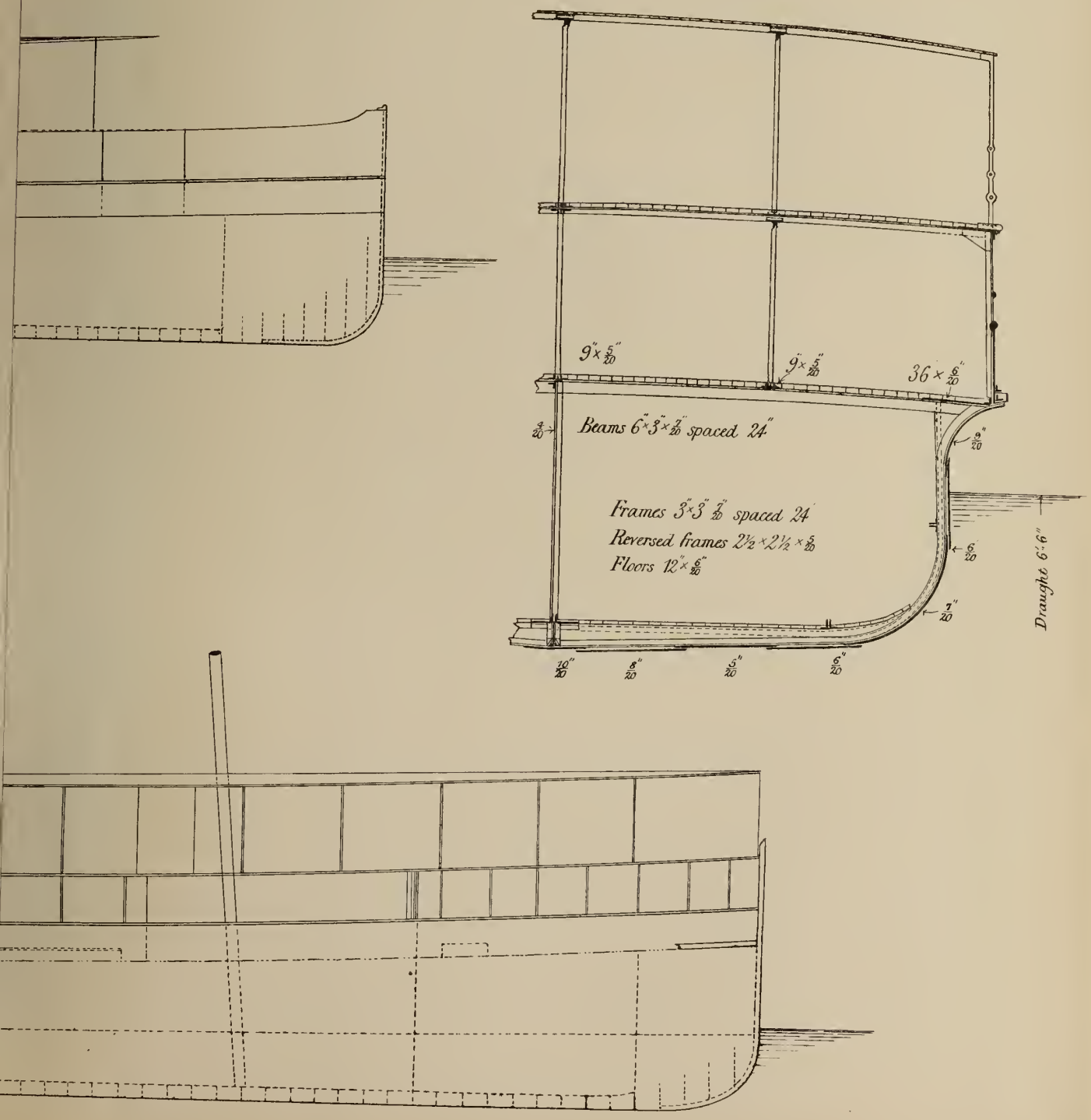


FIG. 2.A


9" × 5/20"
9" × 5/20"
36 × 6/20"
4/20
Beams 6" × 3" × 7/20" spaced 24"
9/20"
Frames 3" × 3" 7/20" spaced 24"
Reversed frames 2½ × 2½ × 5/20
Floors 12" × 6/20"
6/20
7/20"
Draught 6'6"
10/20"
8/20"
5/20"
6/20"

To Illustrate Mr. B. Martell's Paper on light Scantling Steamers.

STEEL TWIN SCREW STEAMER FOR RIVER SERVICE.

Principal Dimensions.
Length...140·3 feet.
Breadth...30·1 „
Depth of Hold 8·0 „
Tonnage.
Gross 312 Net 212.

Fig. 1.

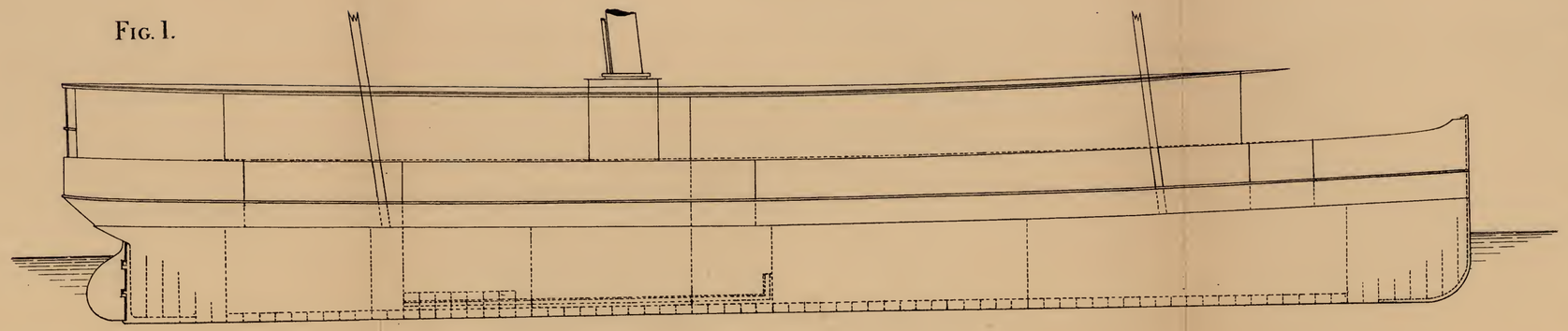


Fig. 1A.

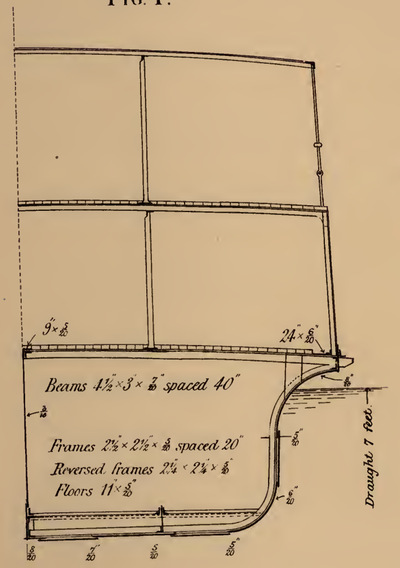
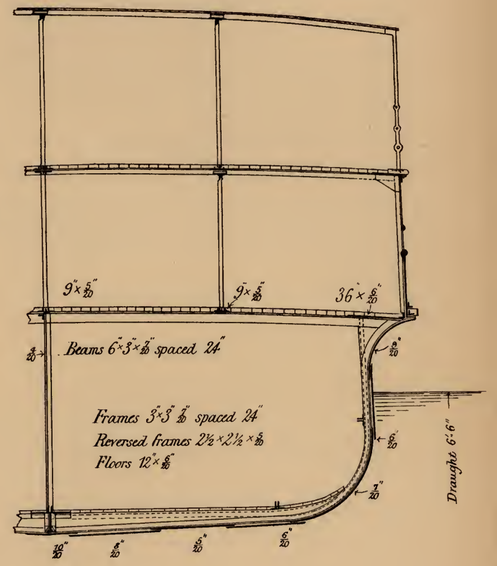


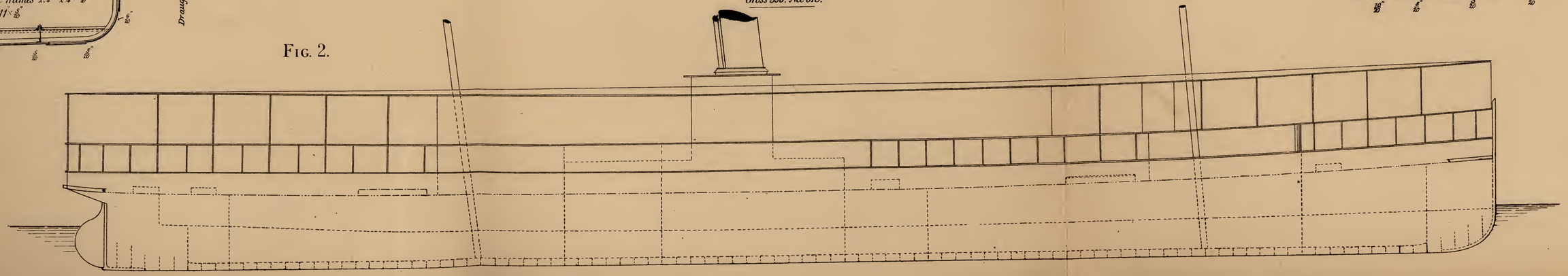
Fig. 2A.

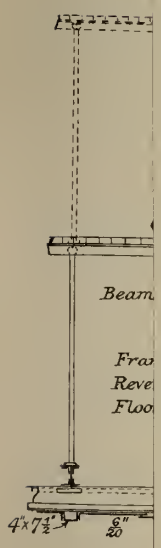


STEEL TWIN SCREW STEAMER FOR RIVER SERVICE

Principal Dimensions.
Length...200·6 feet.
Breadth...34·3 „
Depth of Hold 9·7 „
Tonnage.
Gross 556. Net 378.

Fig. 2.




Beam
Fra
Reve
Floo
4"x7½"
8"
20"

To Illustrate Mr. B. Marteli's Paper on light Scantling Steamers.

STEEL TWIN SCREW STEAMER FOR SHORT COASTING AND RIVER SERVICE.

Principal Dimensions
Length.....140·3 feet.
Breadth.....22·5 „ .
Depth of Hold...7·7 „ .

Tonnage
Gross 202. Net 121.

FIG. 1A.

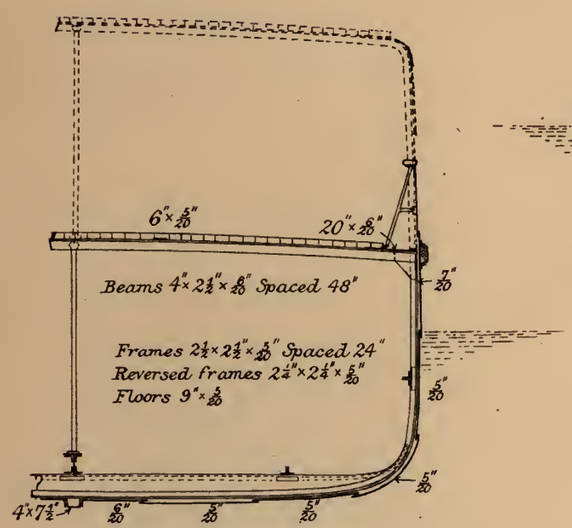
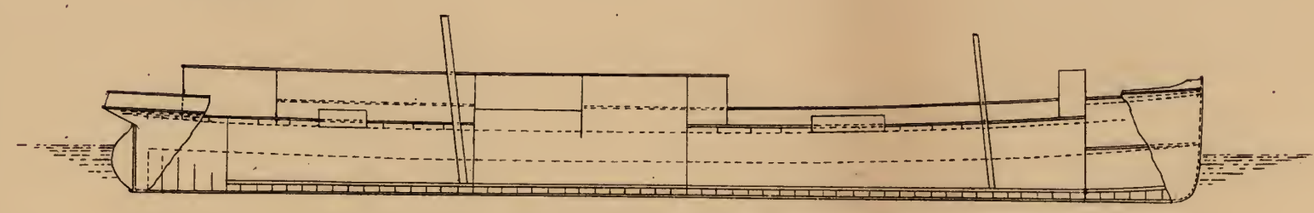


FIG. 1.



STEEL SCREW STEAMER FOR SHORT COASTING AND RIVER SERVICE.

Principal Dimensions
Length.....190·0 feet.
Breadth.....26·1 „ .
Depth of Hold...12·6 „ .

Tonnage
Gross 572. Net 389.

FIG. 2.

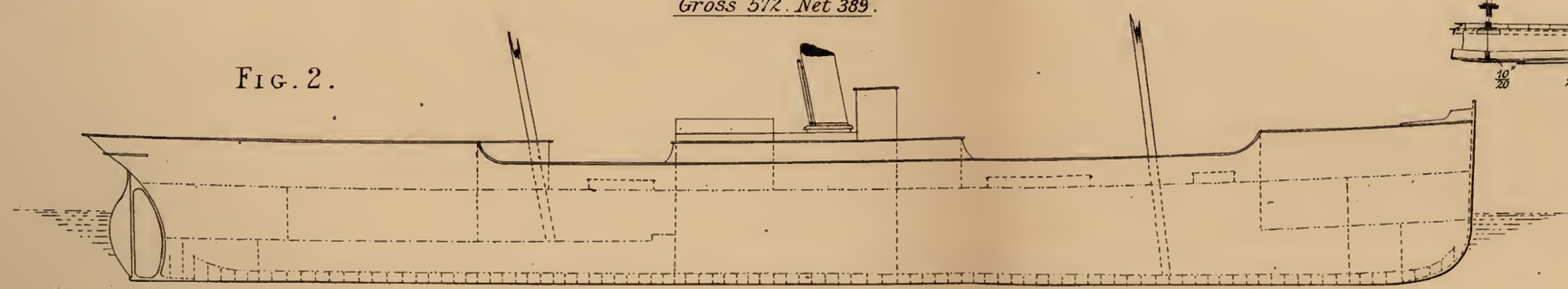


FIG. 2A.

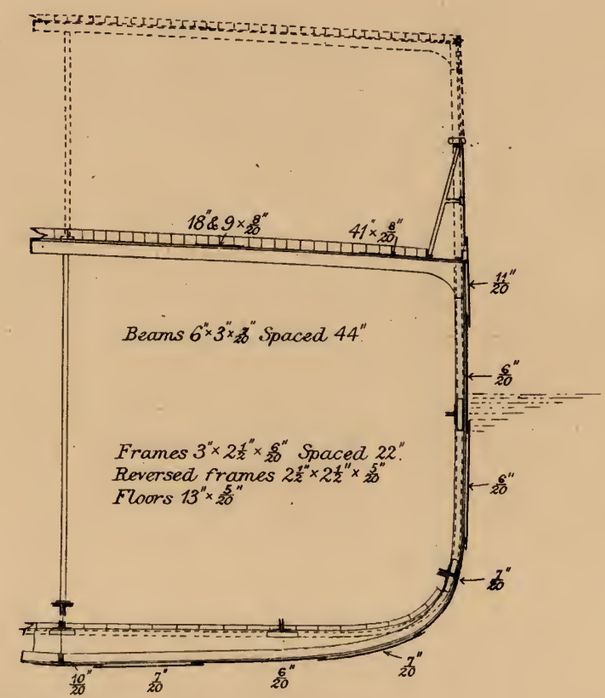
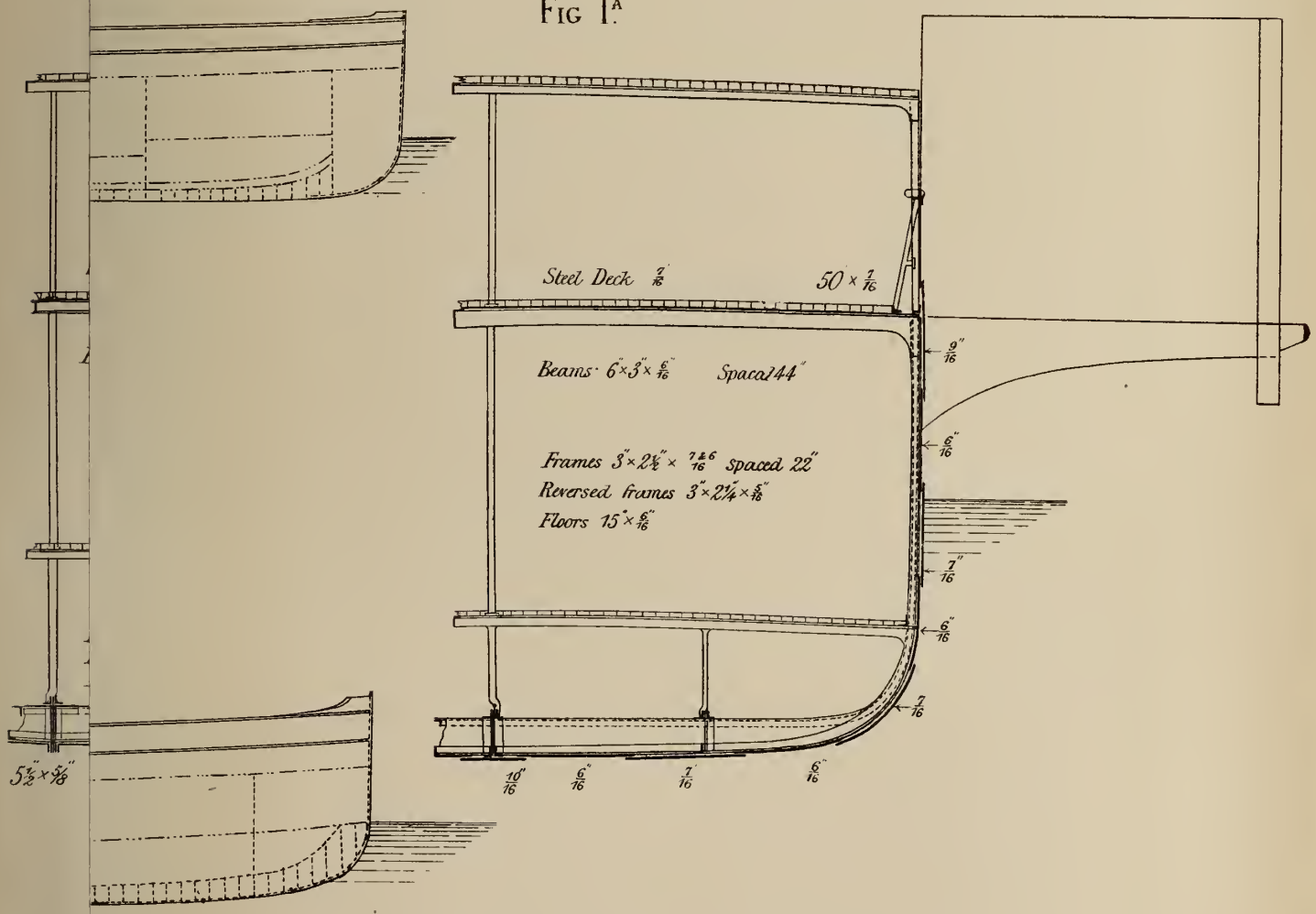


Fig 1.A


Steel Deck 7/16
50 × 7/16
Beams 6"×3"×6/16 Spaced 44"
Frames 3"×2½"×7&6/16 spaced 22"
Reversed frames 3"×2¼"×5/16"
Floors 15"×6/16"
9/16"
6/16"
7/16"
6/16"
7/16
10/16"
6/16"
7/16
6/16"
5½"×5/16"

To Illustrate Mr. B. Martell's Paper on light Scantling Steamers.

STEEL PADDLE STEAMER FOR CHANNEL SERVICE.

Principal Dimensions.
Length 250·6 feet.
Breadth 29·1 „
Depth of Hold 14·0 „
Tonnage.
Gross 804. Net 365.

Fig. 1.

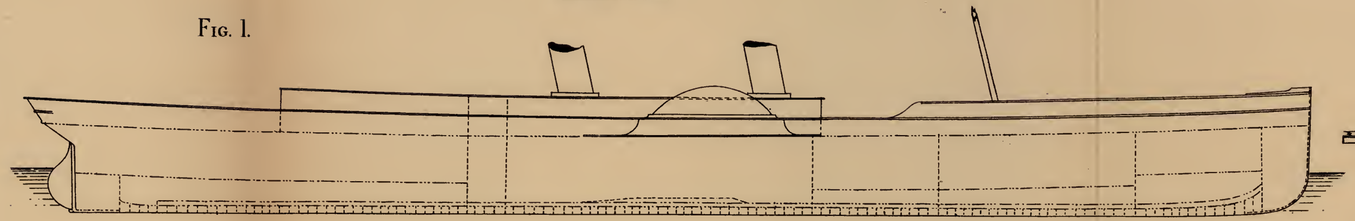
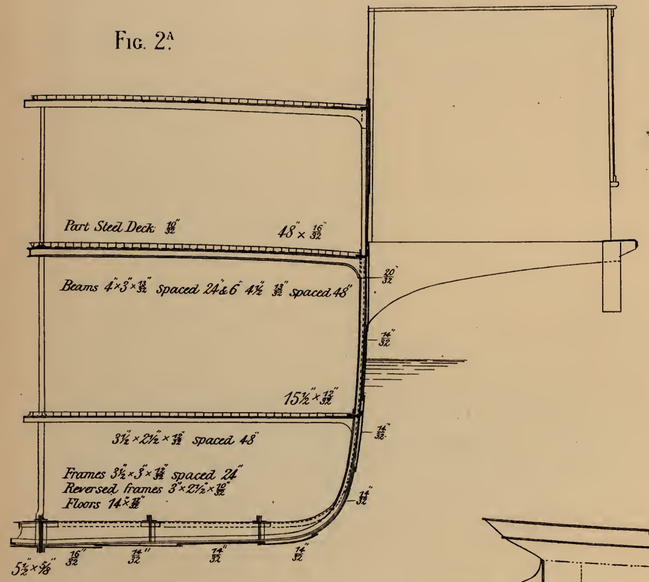


Fig. 2A.



STEEL PADDLE STEAMER FOR CHANNEL SERVICE.

Principal Dimensions.
Length 280·0 feet
Breadth 33·0 „
Depth of Hold 13·8 „
Tonnage.
Gross 951. Net 146.

Fig. 2.

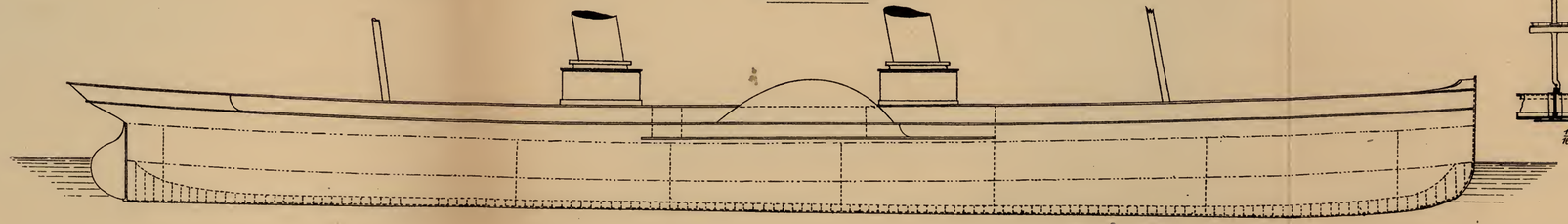


Fig 1A.

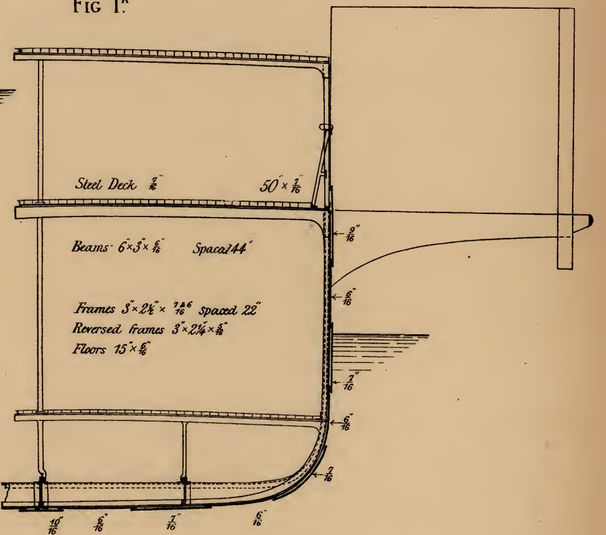
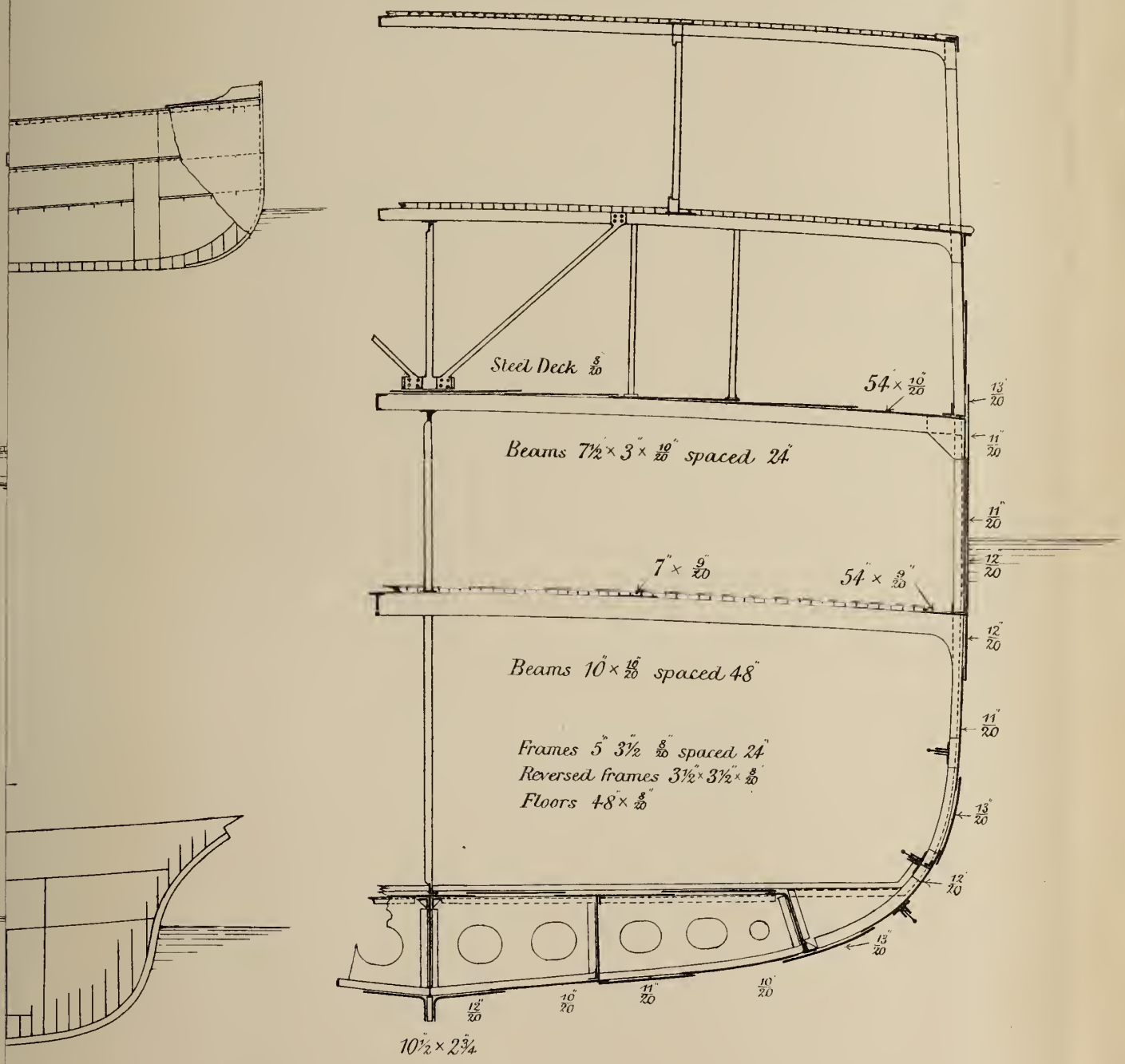


FIG. 2A.


Steel Deck 5/20"
54" × 10/20"
13/20"
Beams 7½" × 3" × 10/20" spaced 24"
11/20"
11/20"
12/20"
7" × 9/20"
54" × 9/20"
12/20"
Beams 10" × 16/20" spaced 48"
11/20"
Frames 5" 3½" 8/20" spaced 24"
Reversed frames 3½" × 3½" × 8/20"
Floors 48" × 8/20"
13/20"
12/20"
13/20"
12/20"
10/20"
11/20"
10/20"
10½" × 2¾"

To Illustrate Mr. B. Martell's Paper on light Scantling Steamers.

STEEL TWIN SCREW STEAMER FOR LONG COASTING SERVICE.

Principal Dimensions.
Length... 275·0 feet.
Breadth... 34·7 „
Depth of Hold 19·5 „
Tonnage.
Gross 1654. Net 966.

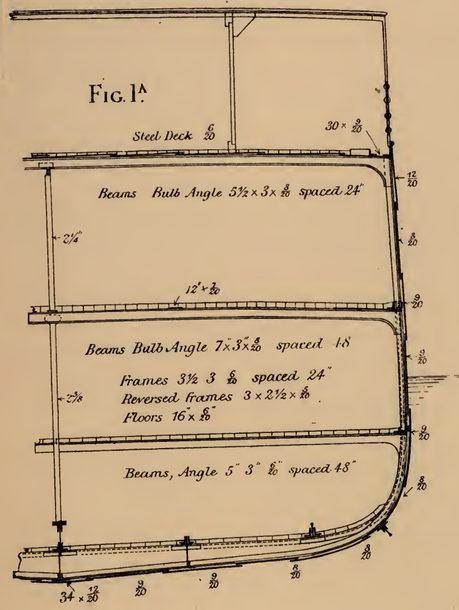
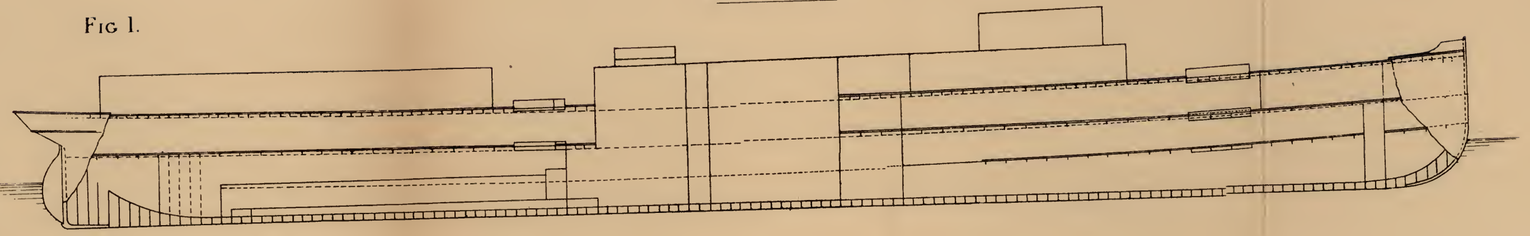


Fig. 1A.

Fig 1.



STEEL SCREW STEAMER FOR LONG COASTING SERVICE.

Principal Dimensions.
Length 350·0 feet.
Breadth 42·1 „
Depth of Hold 19·5 „
Tonnage.
Gross 2242. Net 1488.

Fig. 2.

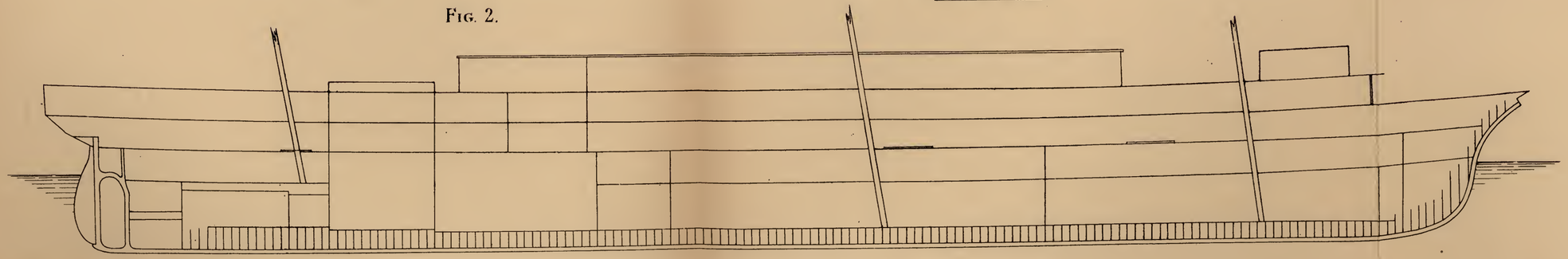
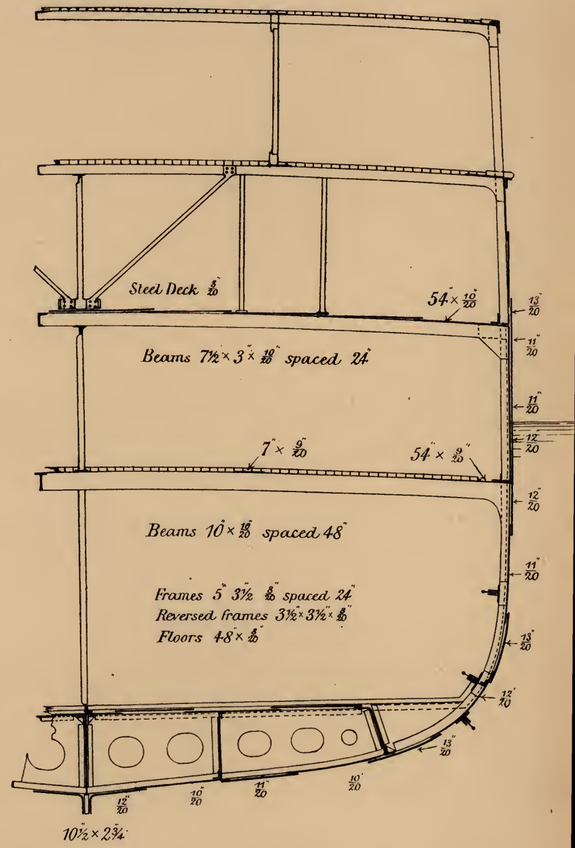


Fig. 2A.



To Illustrate Mr. B. Martell's Paper on light Scantling Steamers.

STEEL PADDLE STEAMER FOR CHANNEL SERVICE

Principal Dimensions
Length... 286·5 feet.
Breadth .. 35·3 „ .
Depth of Hold 22·9 „ .

Tonnage
Gross 1660. Net 871.

FIG. 1.

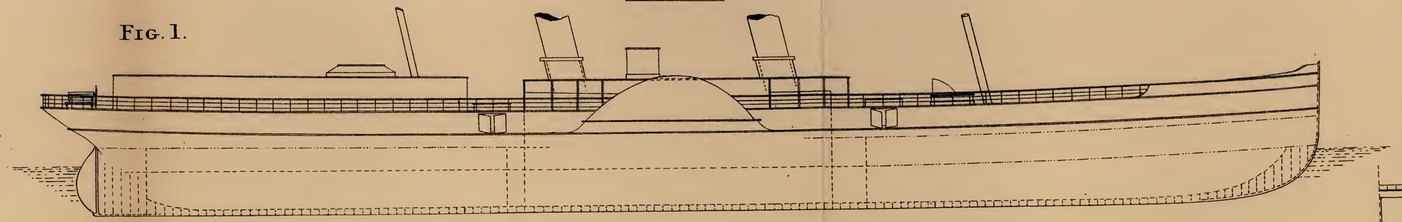
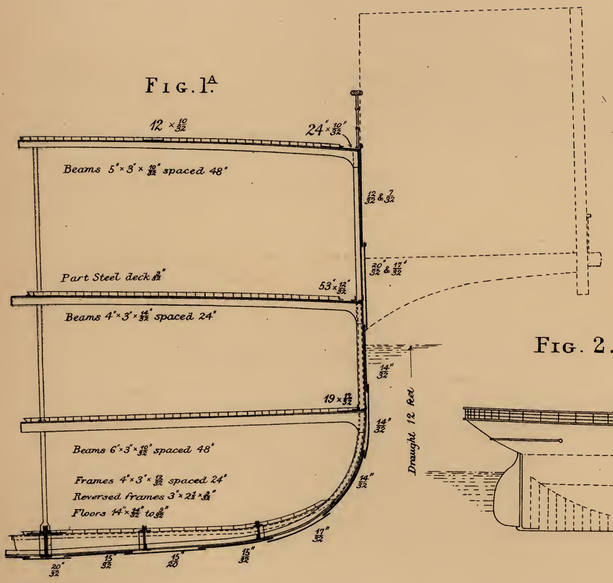


FIG. 1A.



STEEL PADDLE STEAMER FOR CHANNEL SERVICE

Principal Dimensions
Length 320·0 feet.
Breadth 35·5 „ ...
Depth of Hold 23·5 „ ...

Tonnage
Gross 1900. Net 1000.

FIG. 2.

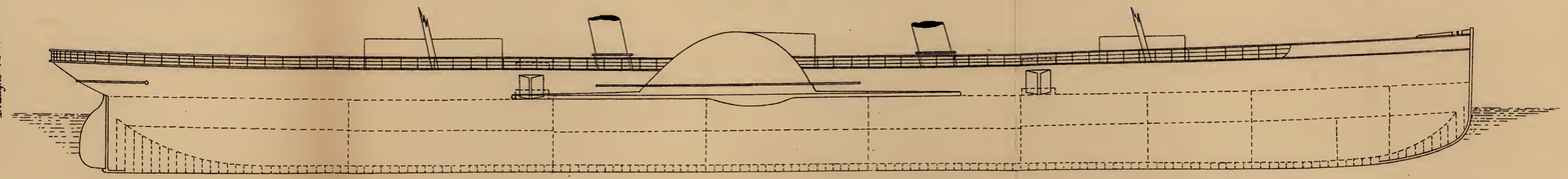
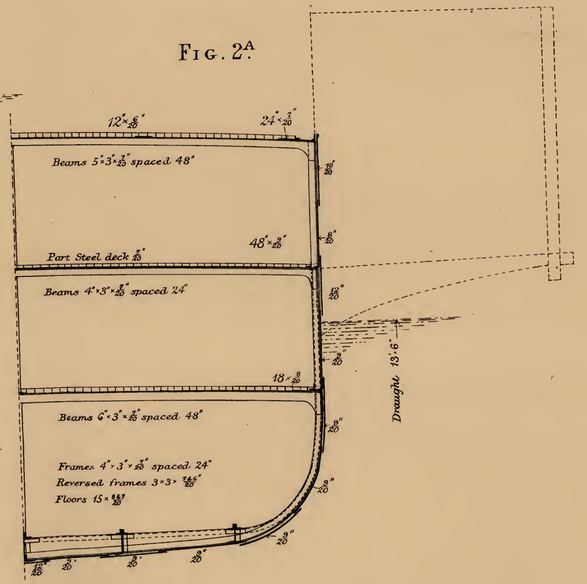


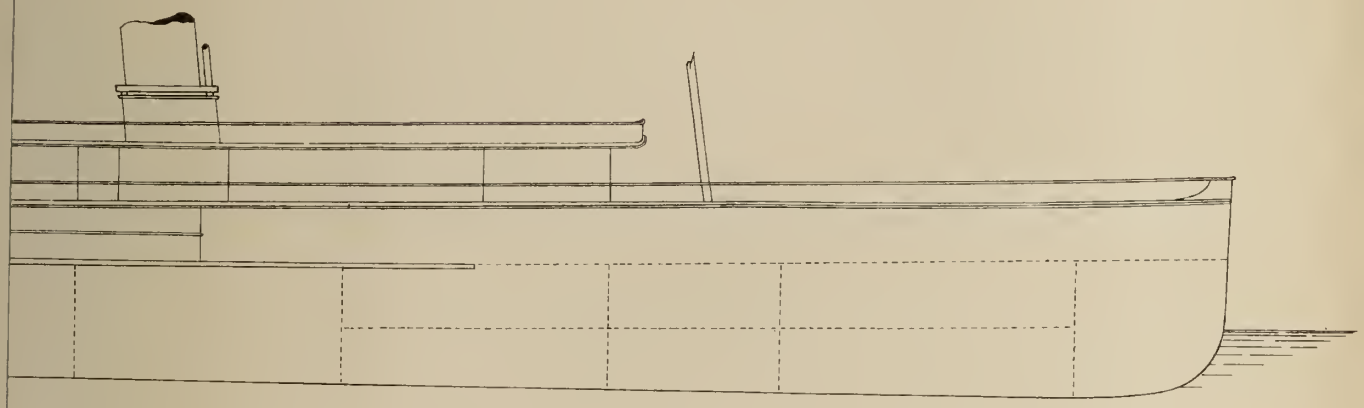
FIG. 2A.



SPECIAL EXCURSION SERVICE.

s.

90.



To Illustrate Mr. B. Martell's Paper on light Scantling Steamers.

STEEL PADDLE STEAMER FOR CONTINENTAL & SPECIAL EXCURSION SERVICE.

Principal Dimensions.

Length.....330·0 feet.
Breadth.....40·0 "
Depth of Hold 21·0 "

Tonnage.

Gross 2200..... Net 1090.

Fig. 1A

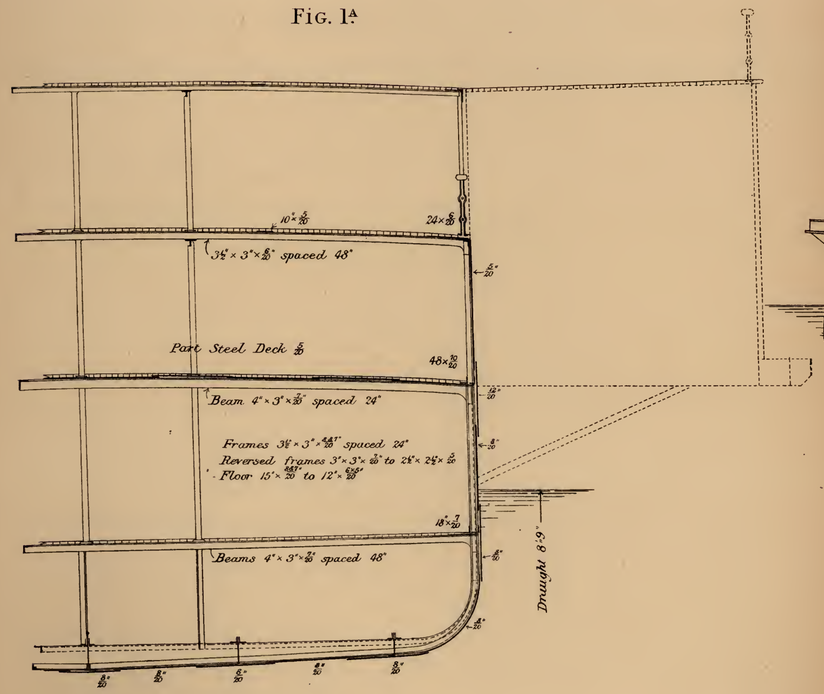
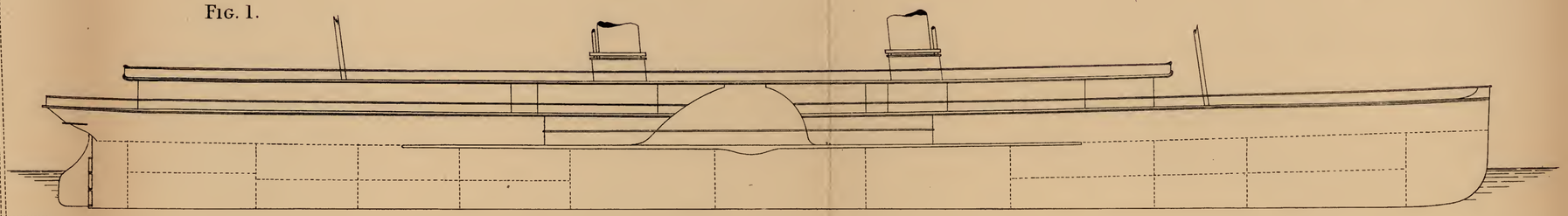


Fig. 1.



CE.

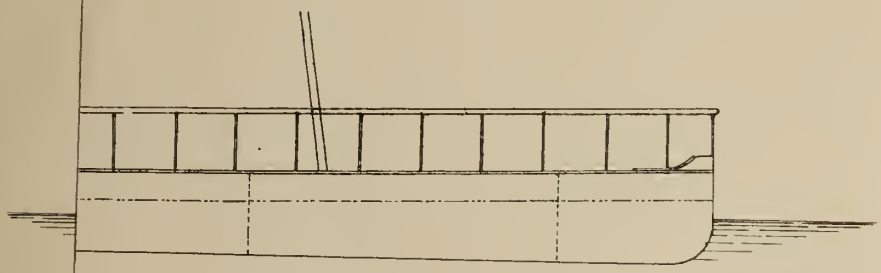


FIG. 1A.

CE.

Ba

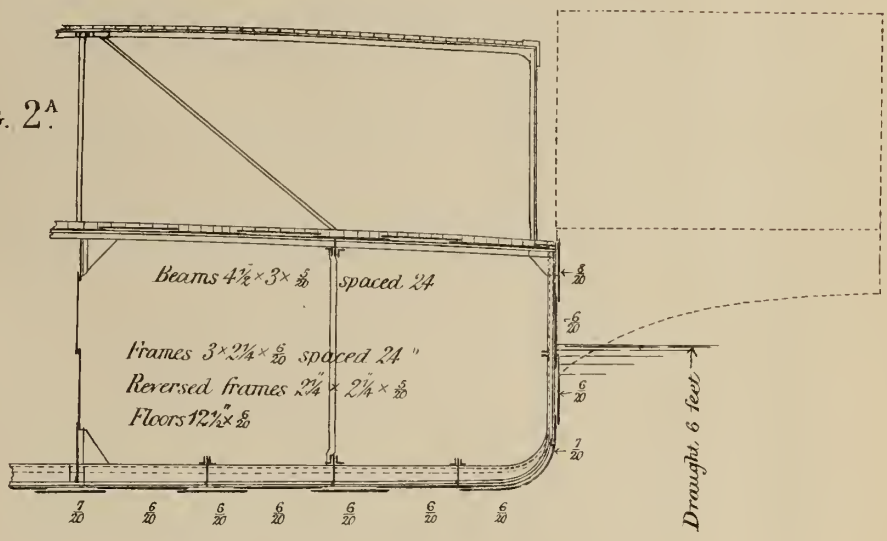
Fra

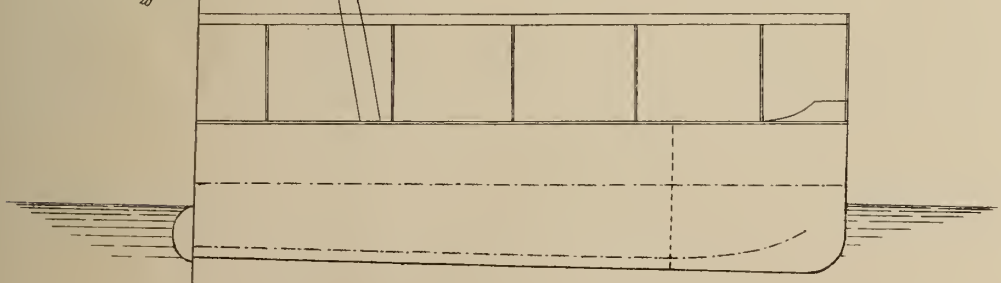
Rev

Flo

6/20

FIG. 2A.





To Illustrate Mr. B. Martell's Paper on light Scantling Steamers.

STEEL PADDLE STEAMER FOR SHALLOW RIVER SERVICE.

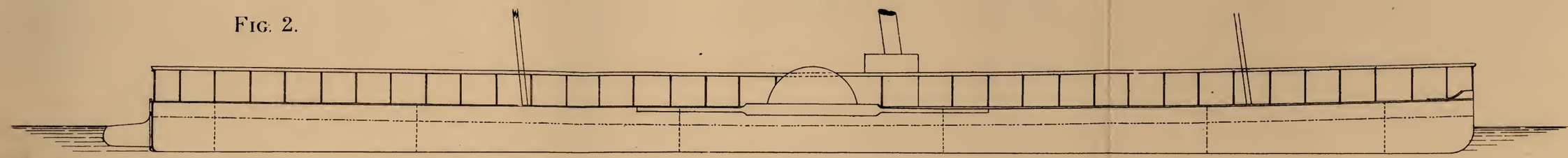
Principal Dimensions.

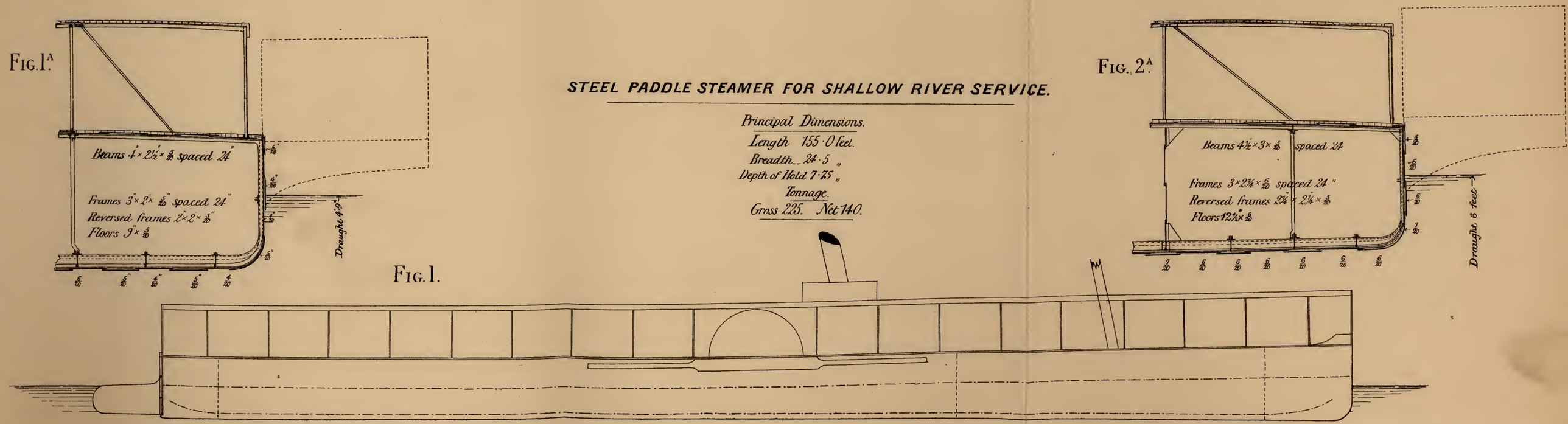
Length 300·0 feet
Breadth 38·0 „
Depth of Hold 10·0 „

Tonnage.

Gross 920. Net 580.

FIG. 2.





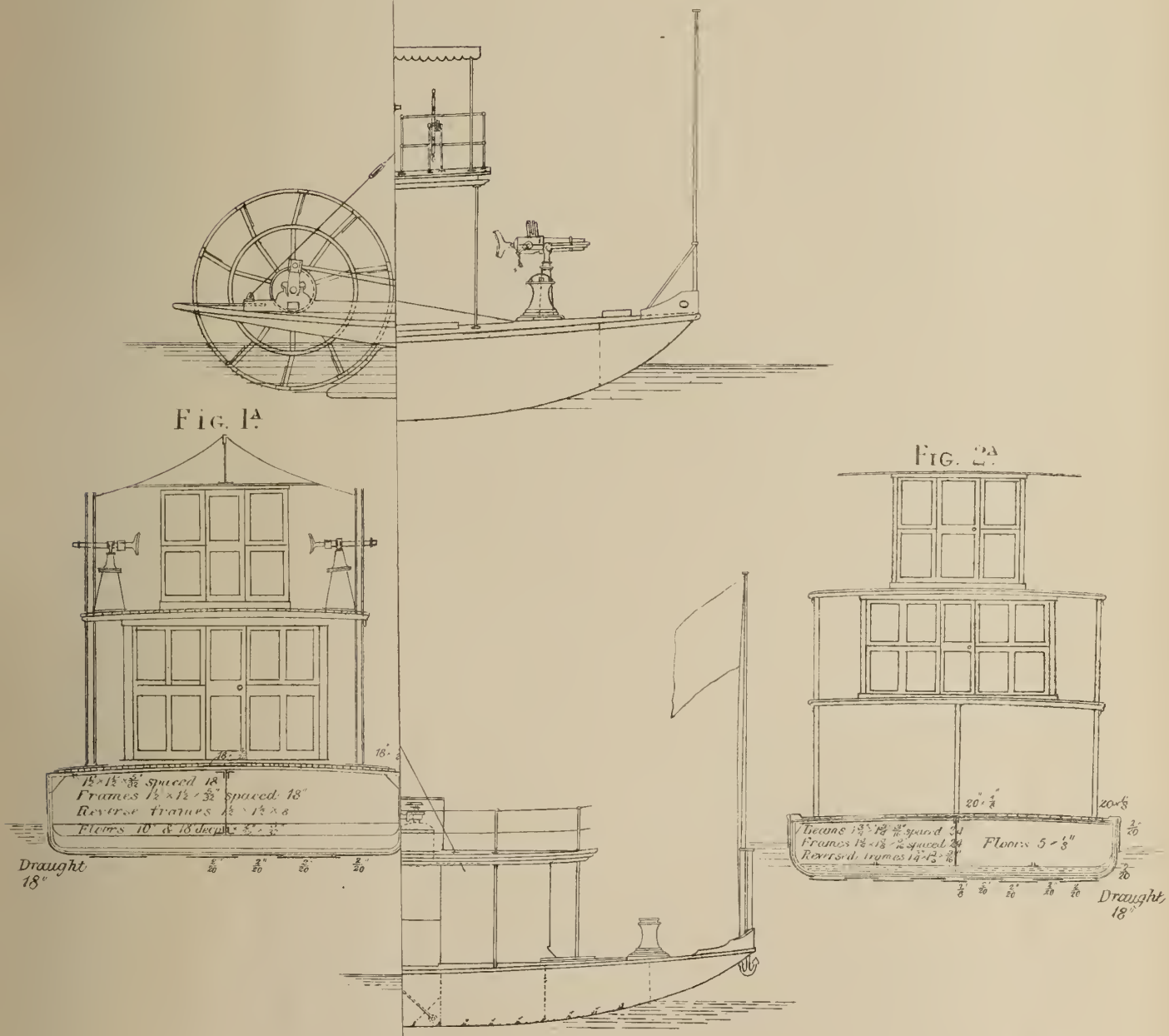


Fig. 1A
Fig. 2A
Frames 1½ × 1½ × 5/32 spaced 18"
Reverse frames 1½ × 1½ × 8
Floors 10" & 18" deep
Draught 18"
Floors 5 × 1/8"
Draught 18"

To Illustrate Mr. B. Martell's Paper on light Scantling Steamers.

Steel Stern Wheel Steamer for Shallow River Service.

Fig. 1.

Principal Dimensions.

Length	100.0 feet
Breadth	18.0
Depth of Hold	3.5

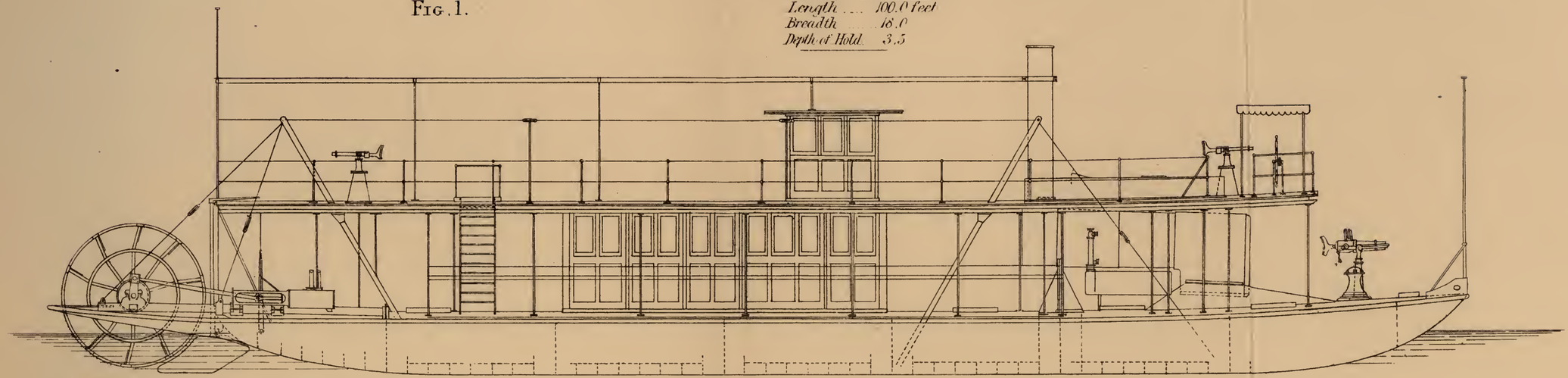
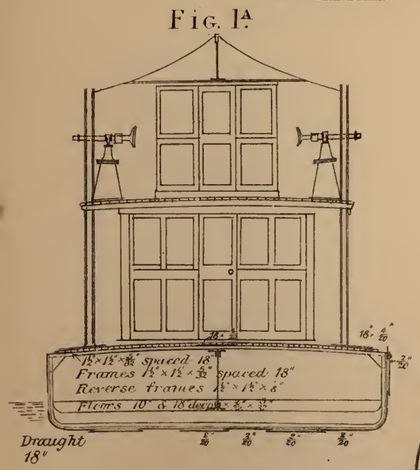


Fig. 1A



Steel Stern Wheel Steamer for Shallow River Service.

Fig. 2.

Principal Dimensions.

Length	130.0 feet
Breadth	24.5
Depth of Hold	4.0

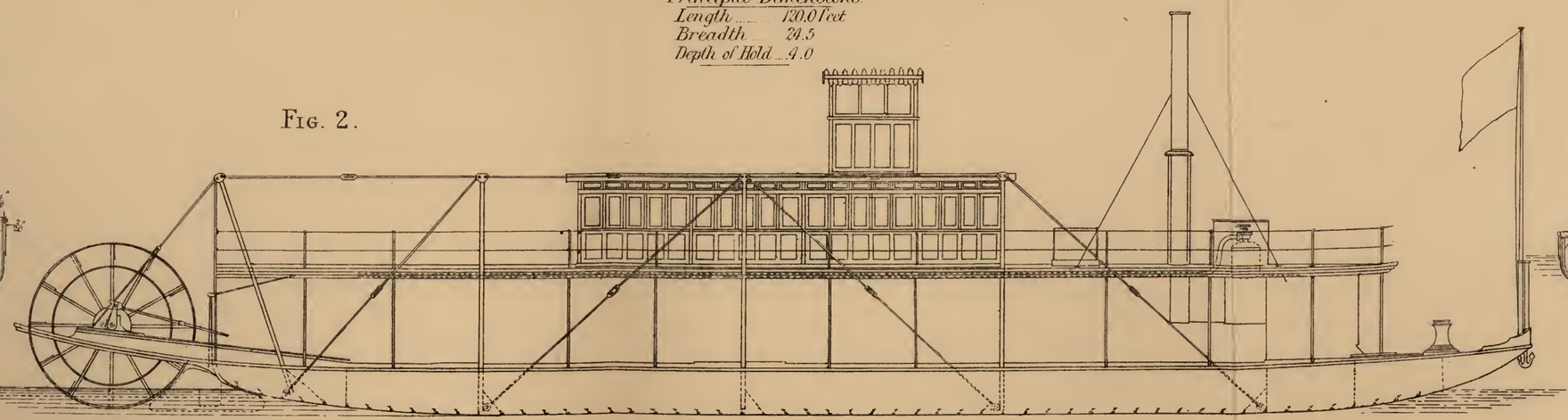
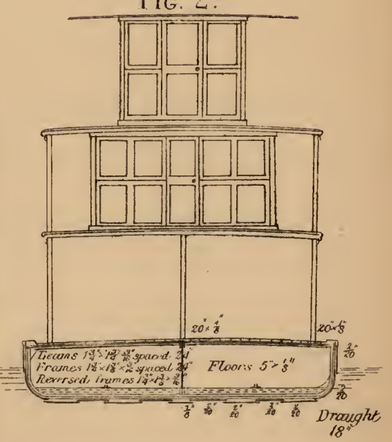


Fig. 2A



Steamers.

ERS.

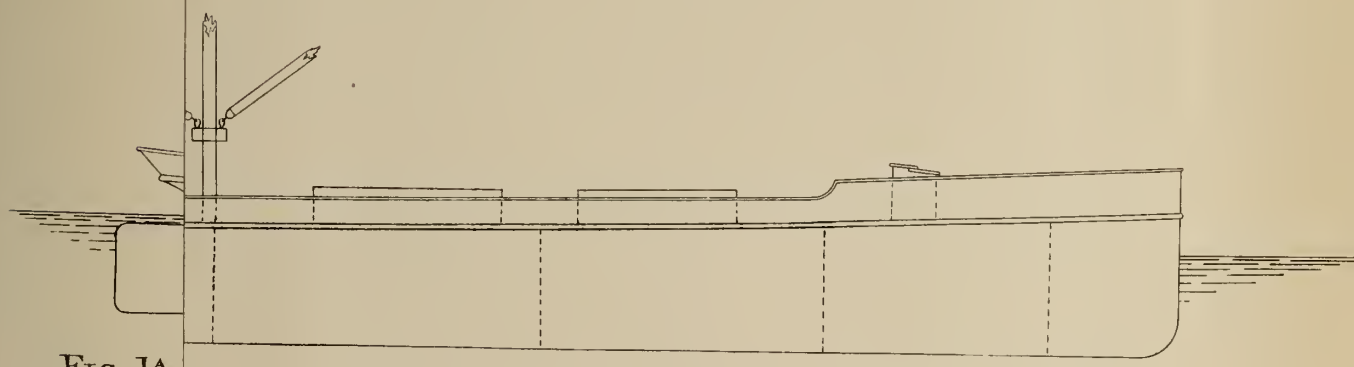


FIG. 1A.

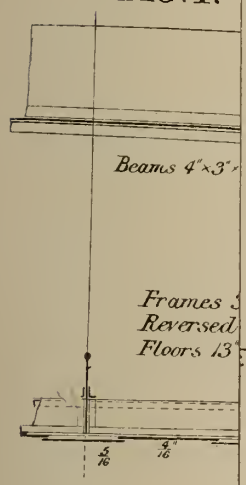
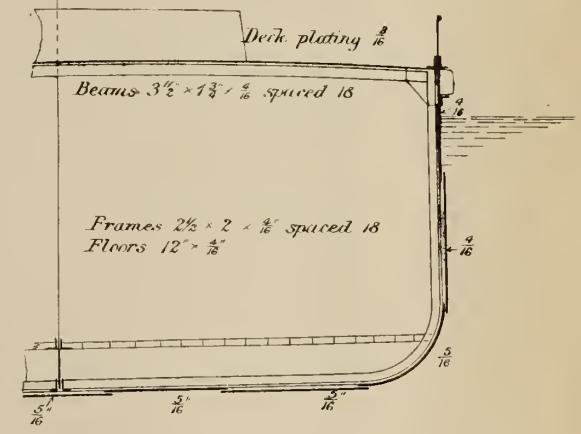
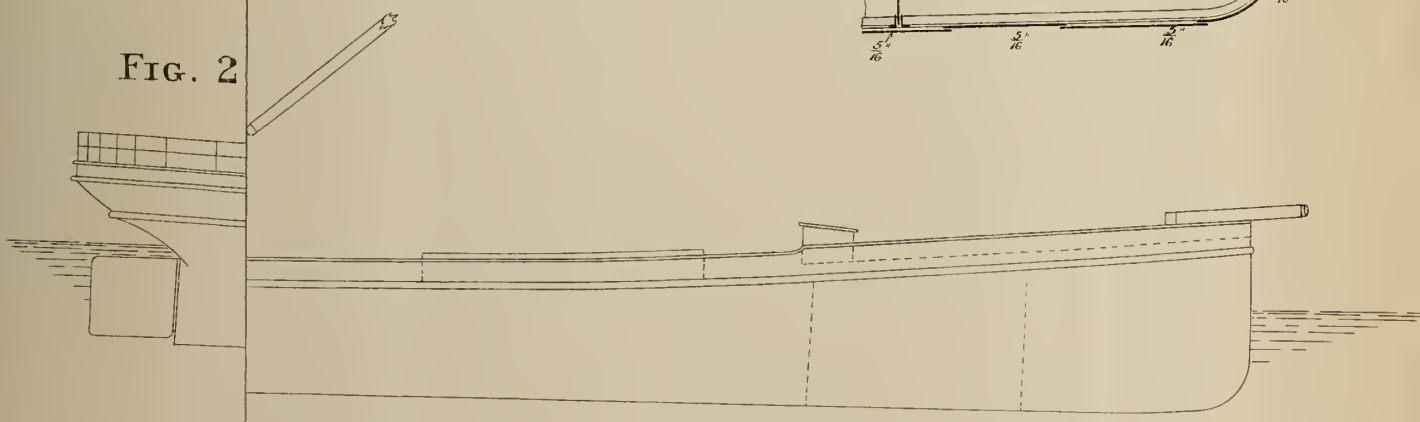


FIG. 2A.



ERS.

FIG. 2



To Illustrate Mr B. Martell's Paper on light Scantling Steamers.

Iron Twin Screw Steam Barge for the Rhine & Similar Rivers.

Principal Dimensions.
Length..... 230 feet
Breadth..... 26.6 "
Depth of Hold 8.3 "

Fig. 1.

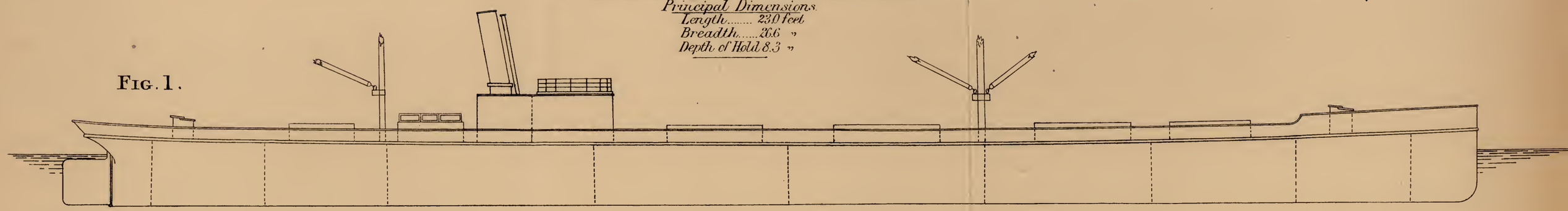
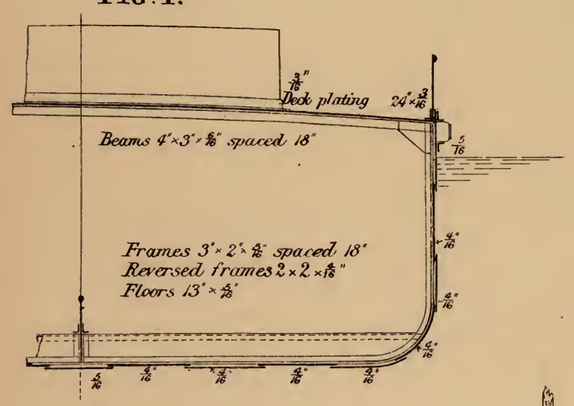


Fig. 1A.



Steel Twin Screw Steam Barge for the Rhine & Similar Rivers.

Principal Dimensions.
Length..... 225.0 feet
Breadth..... 20.0 "
Depth of Hold 6.5 "

Fig. 2.

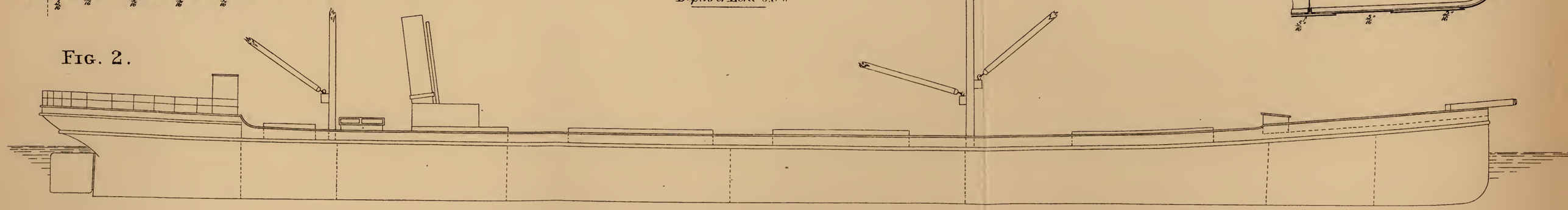
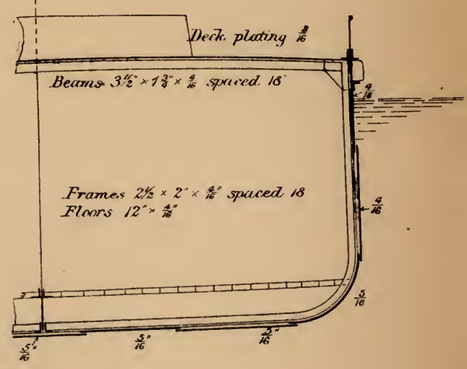
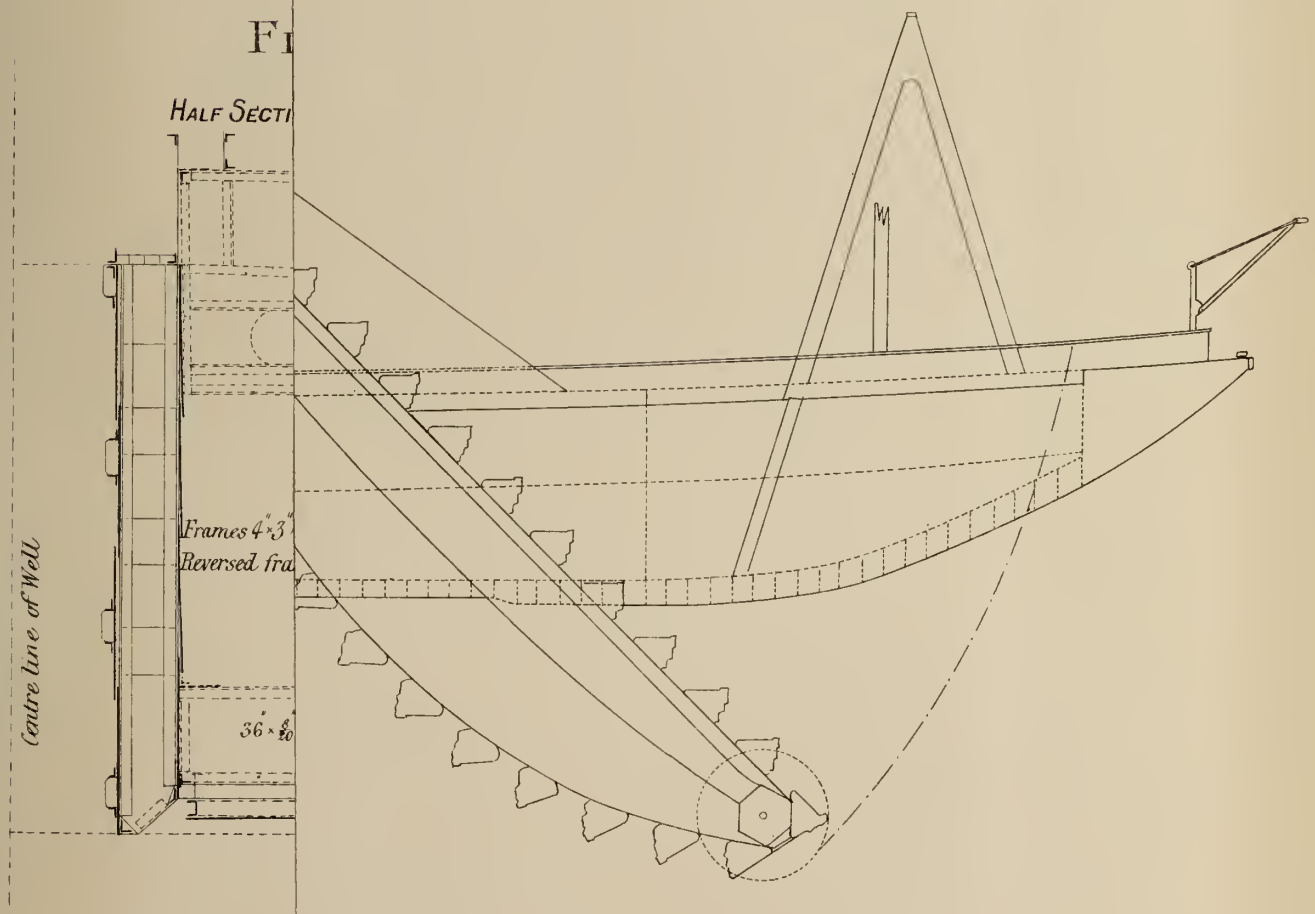


Fig. 2A.



R DREDGER.

F


HALF SECTI
Frames 4"×3"
Reversed fra
36"×$\frac{5}{10}$"
Centre line of Well

To Illustrate Mr. B. Martell's Paper on light Scantling Steamers.

STEEL TWIN SCREW HOPPER DREDGER.

Principal Dimensions

Length	200·5 feet
Breadth	39·1 "
Depth of Hold	15·9 "

Tonnage

Gross 945. Net 449.

FIG. 1A.

HALF SECTION IN WAY OF HOPPER

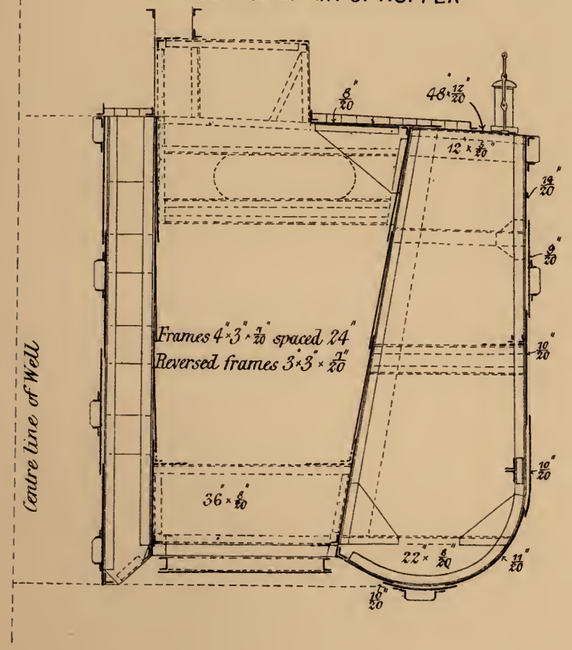


FIG. 1.

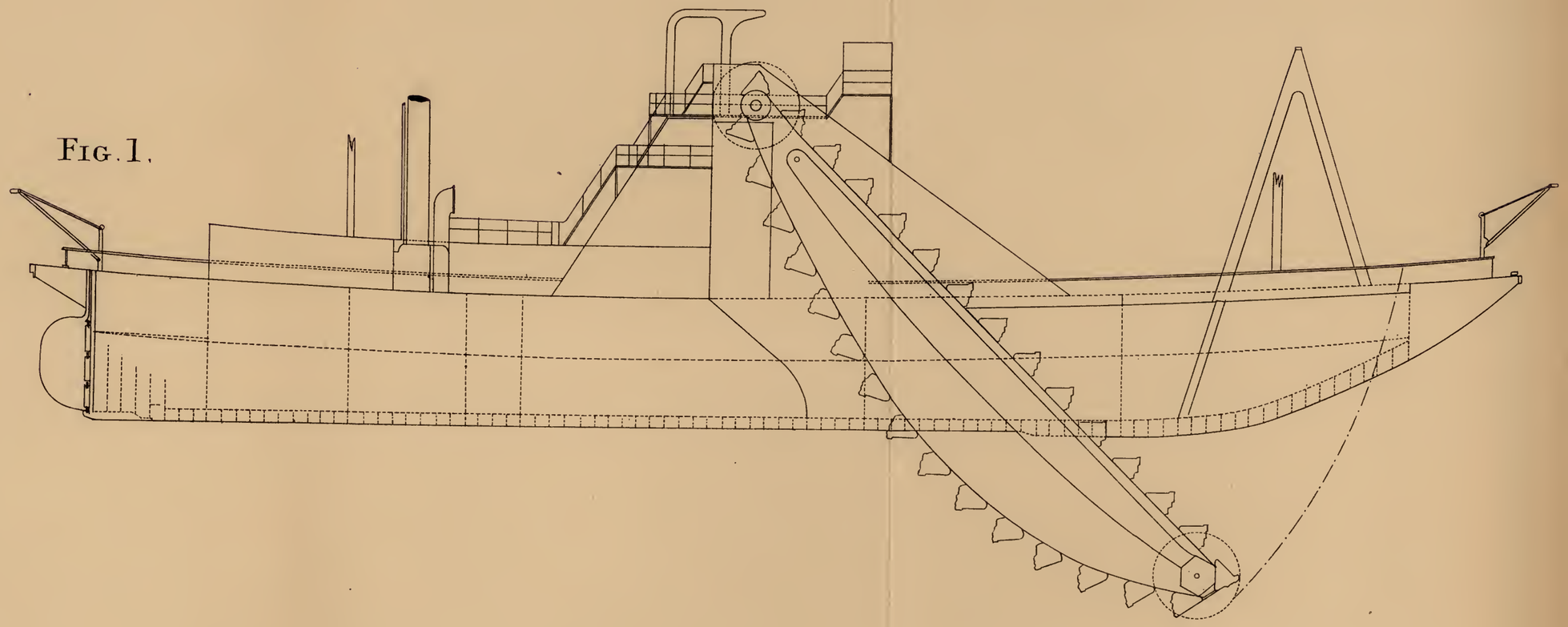
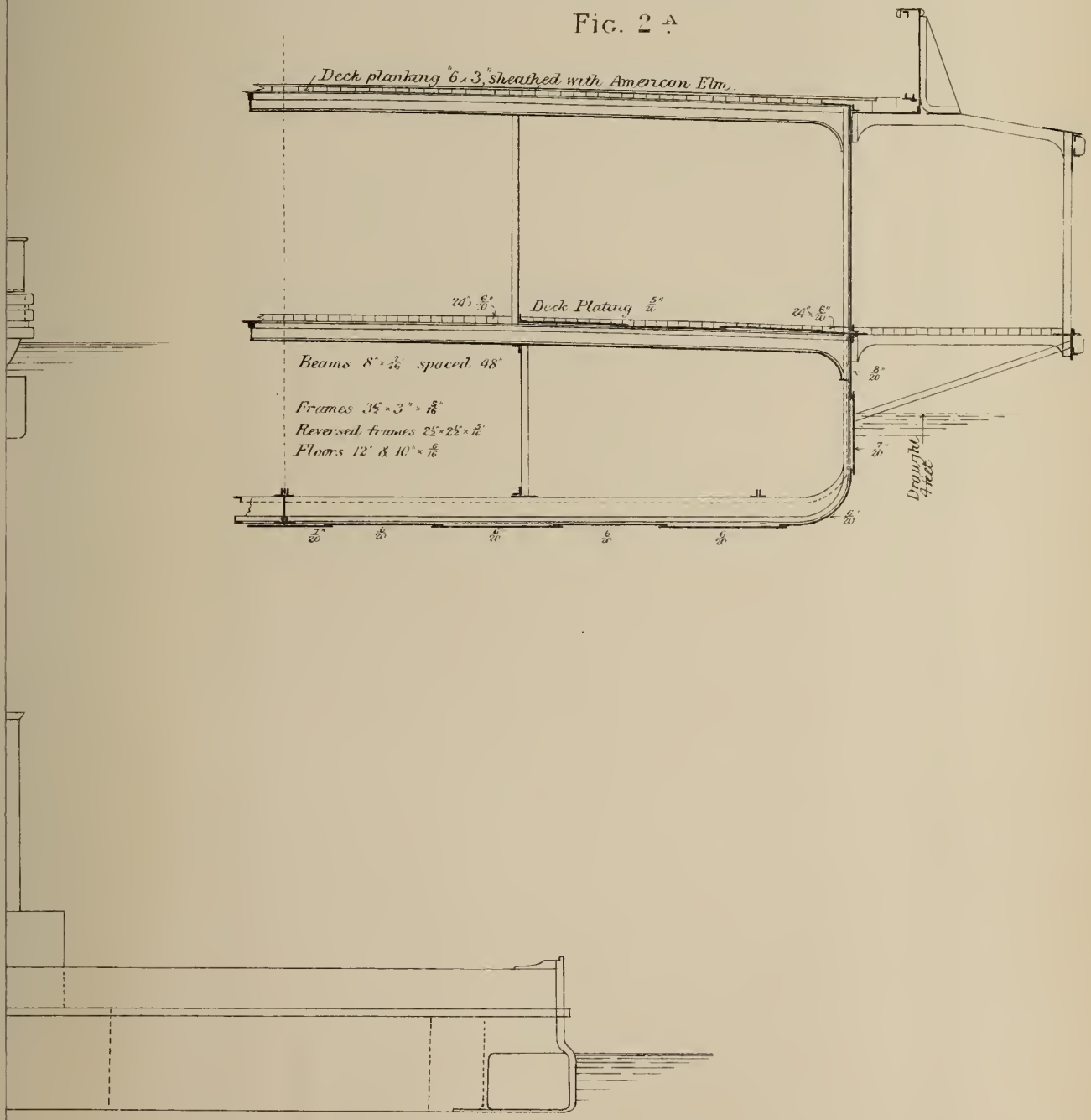


Fig. 2 A


Deck planking 6" x 3" sheathed with American Elm.
24" x 6/20"
Deck Plating 5/24"
24" x 6/20"
Beams 8" x 7/16" spaced 48"
Frames 3½" x 3" x 5/16"
Reversed frames 2½" x 2½" x 5/16"
Floors 12" & 10" x 6/16
8/20"
7/20"
Draught 4 feet
6/20"
7/20"
6/20"
6/20"
6/20"
6/20"

To Illustrate Mr. B. Martell's Paper on light Scantling Steamers.

STEEL DOUBLE TWIN SCREW STEAMER FOR FERRY SERVICE ONLY.

Principal Dimensions.
Length ..... 120 feet
Breadth 40
Depth of Hold 10

Tonnage.
Gross 338 ..... *Net* 230.

Fig. 1.

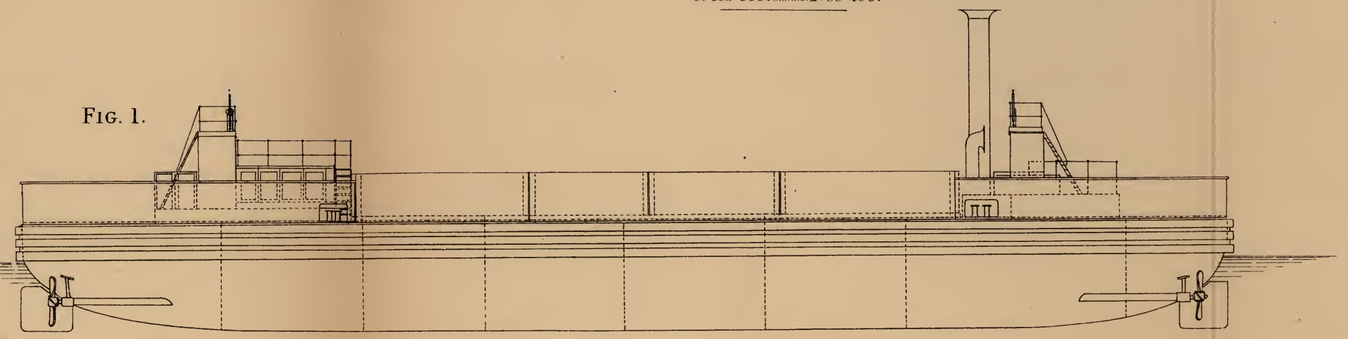


Fig. 1A.

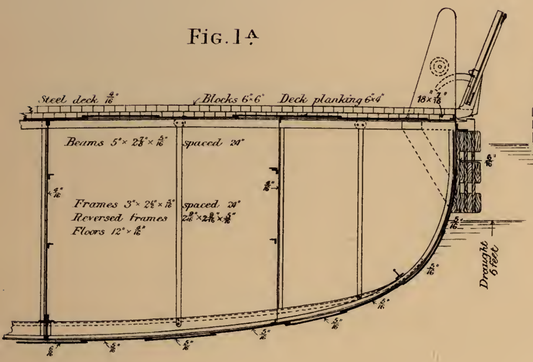
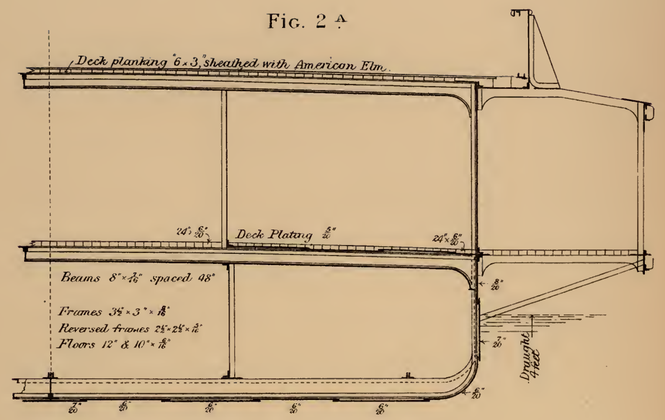


Fig. 2A.

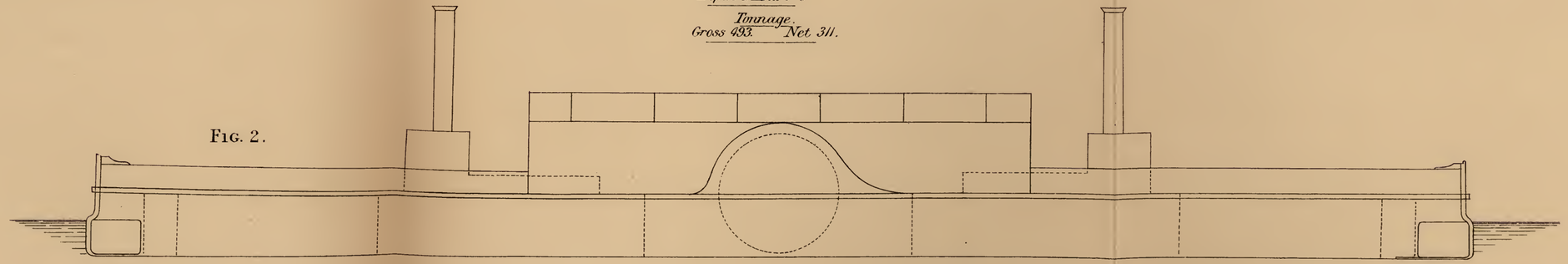


IRON & STEEL PADDLE STEAMER FOR FERRY SERVICE ONLY.

Principal Dimensions.
Length ..... 164·6 feet
Breadth ..... 42·1
Depth of Hold 6·3

Tonnage.
Gross 493. ..... *Net* 311.

Fig. 2.



To Illustrate Monsieur A. Normand's Paper on Water Tube Boilers.

FIGURE 1.

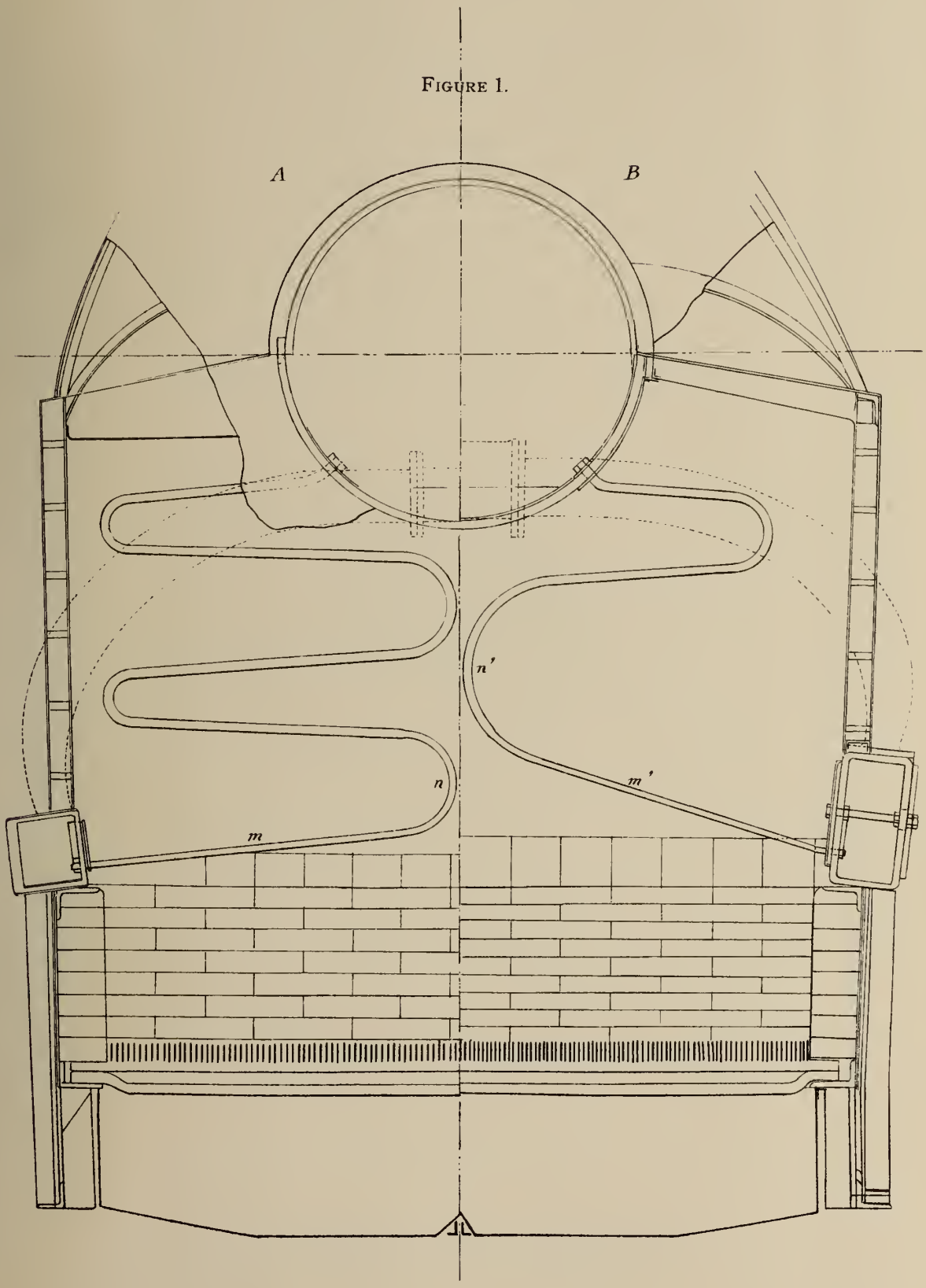


Fig. 2.

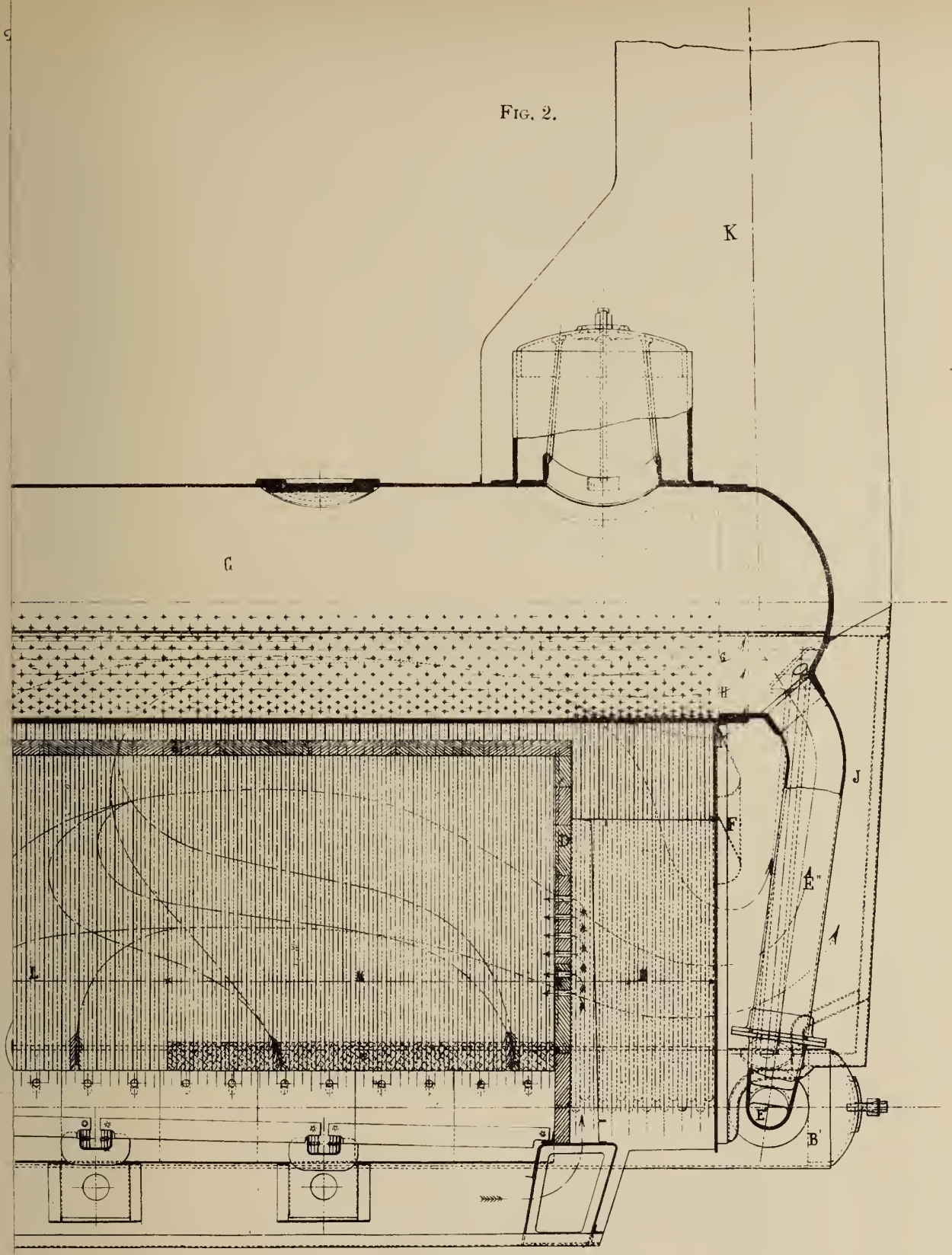
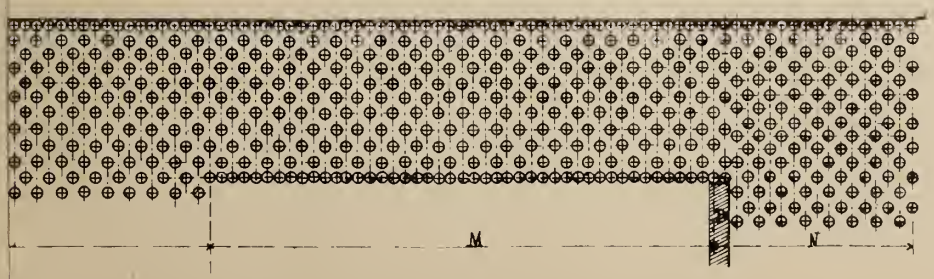


Fig. 5.



To Illustrate Monsieur A. Normand's Paper on Water Tube Boilers

Fig. 3.

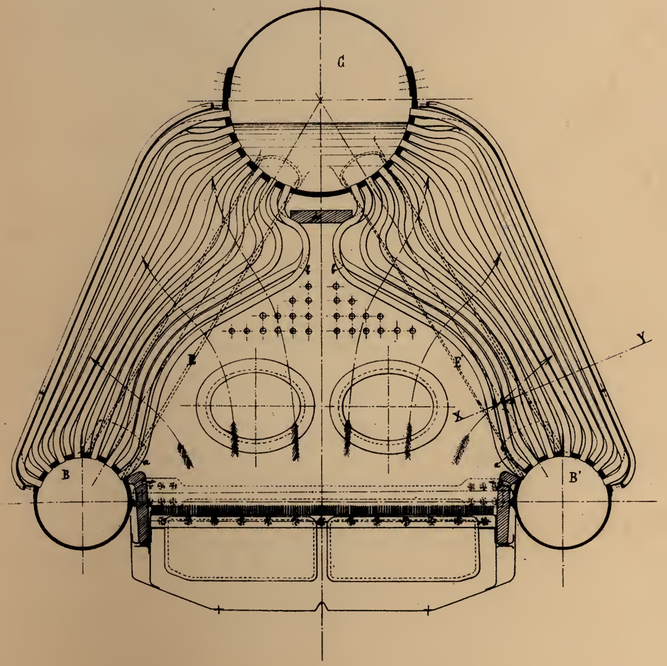


Fig. 4.

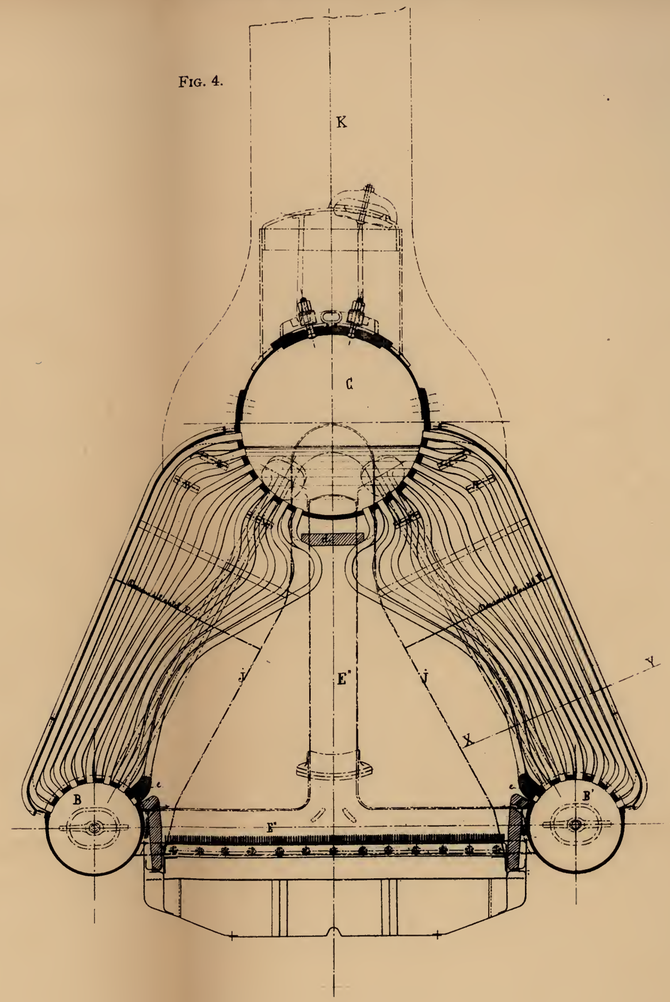


Fig. 2.

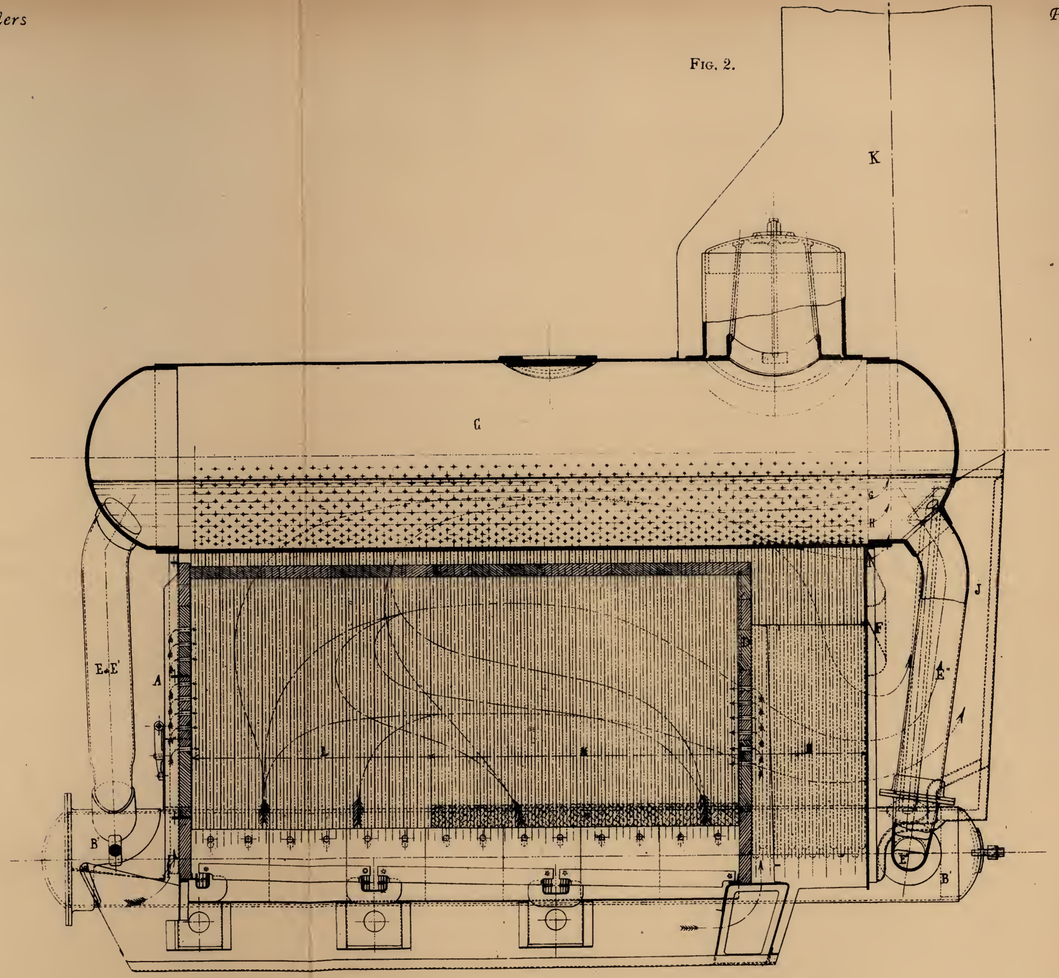


Fig. 5.

To Illustrate Mr. Mark Robinson's Paper on the Niclausse Boiler.

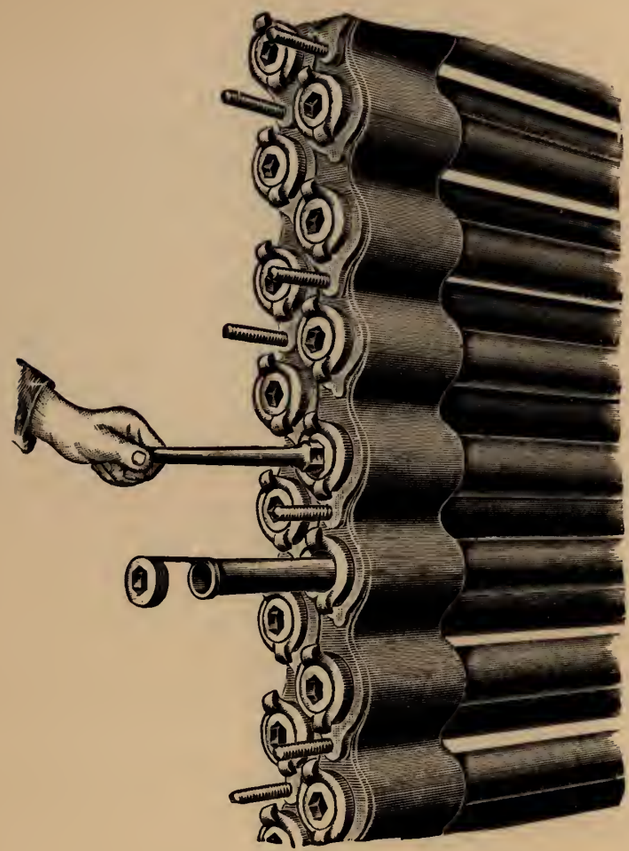


FIG. 6.

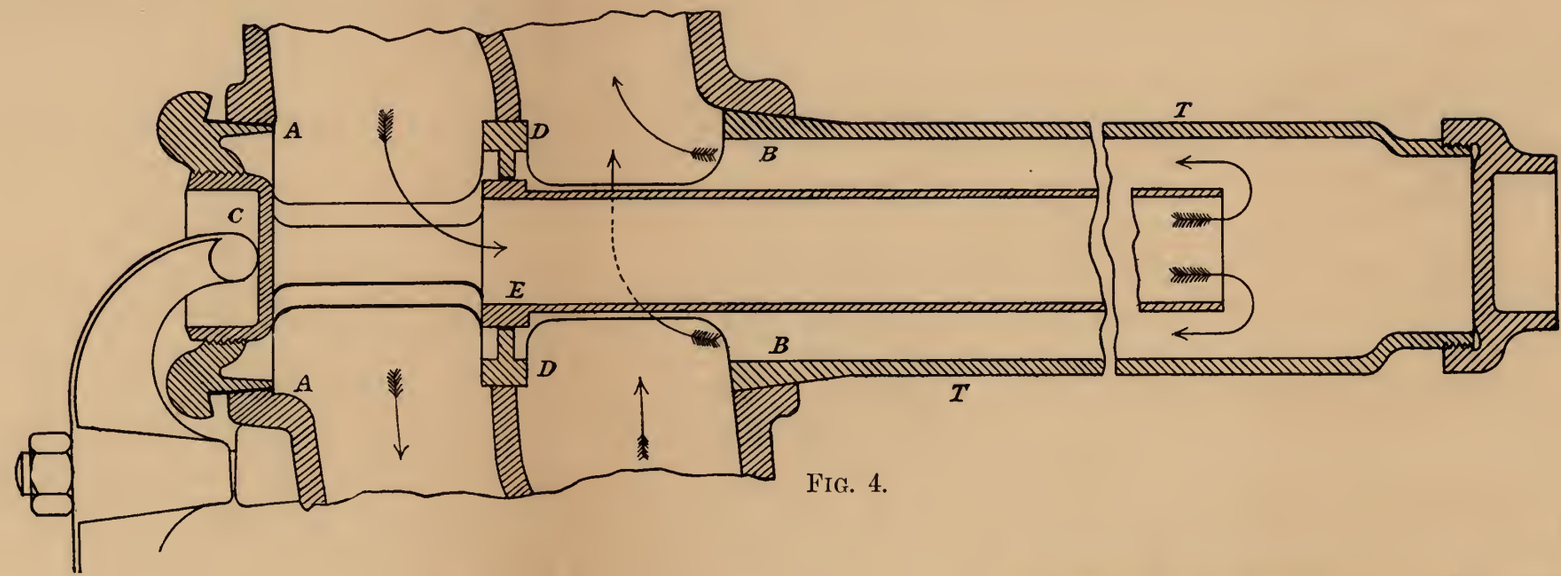


FIG. 4.

FIG. 3.

FIG. 2.

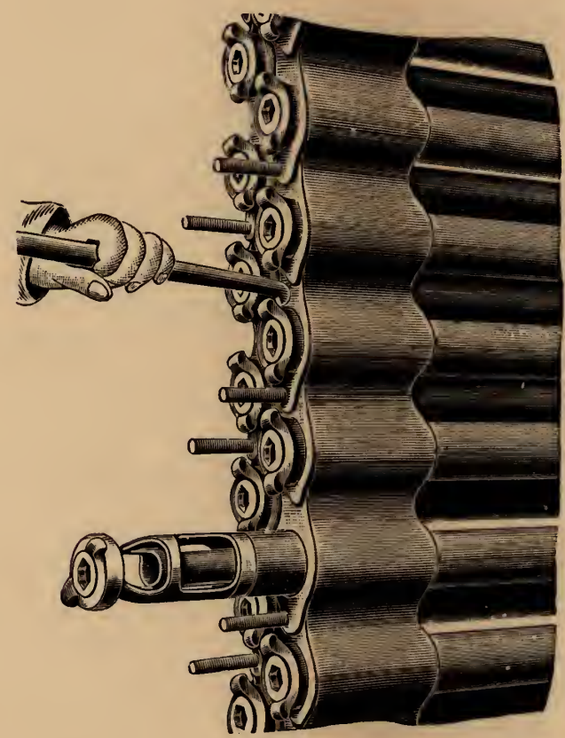


FIG. 7.

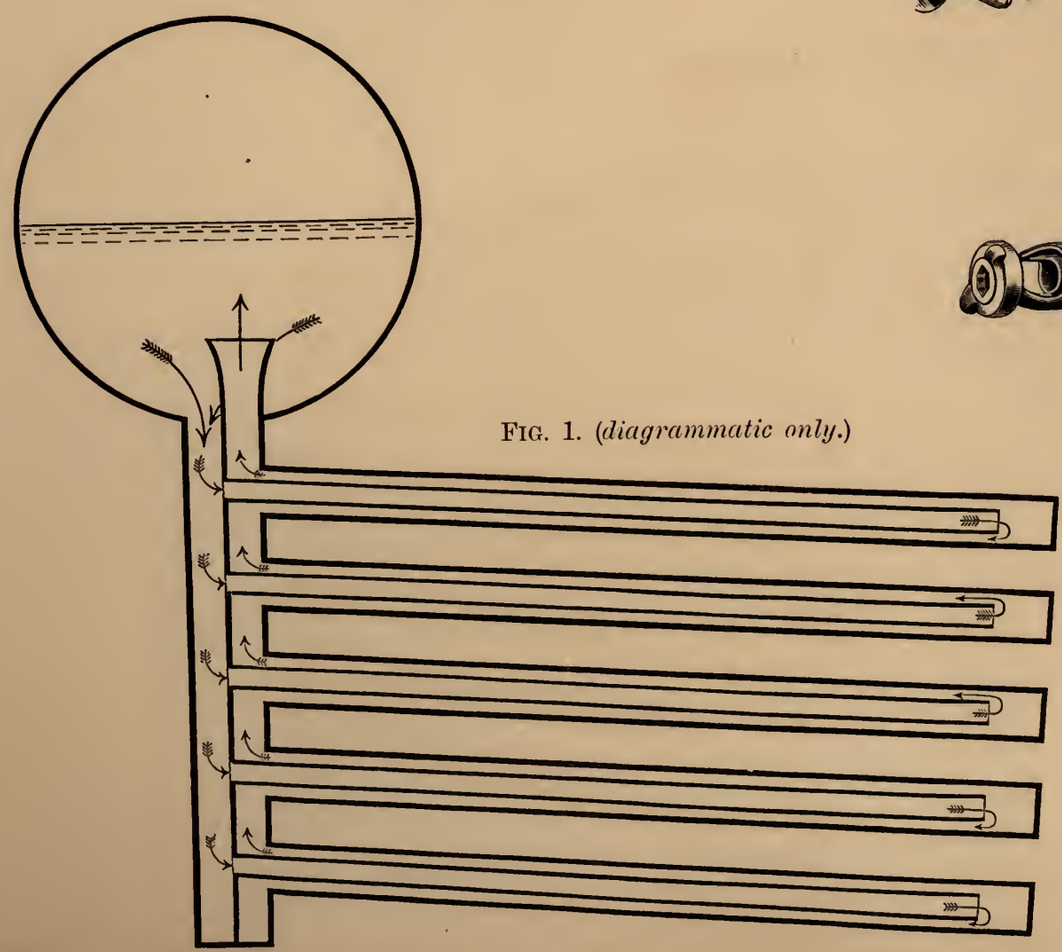


FIG. 1. (*diagrammatic only.*)

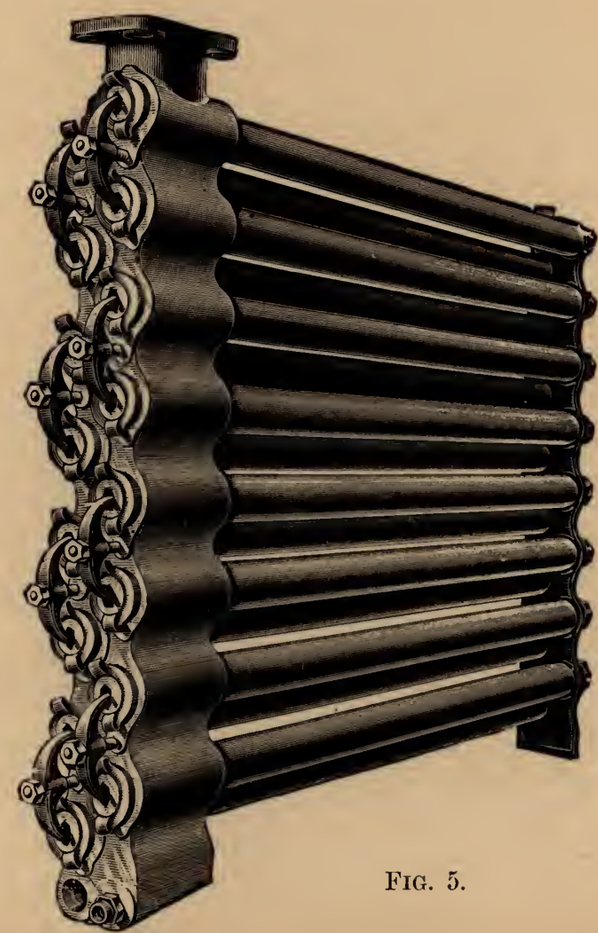
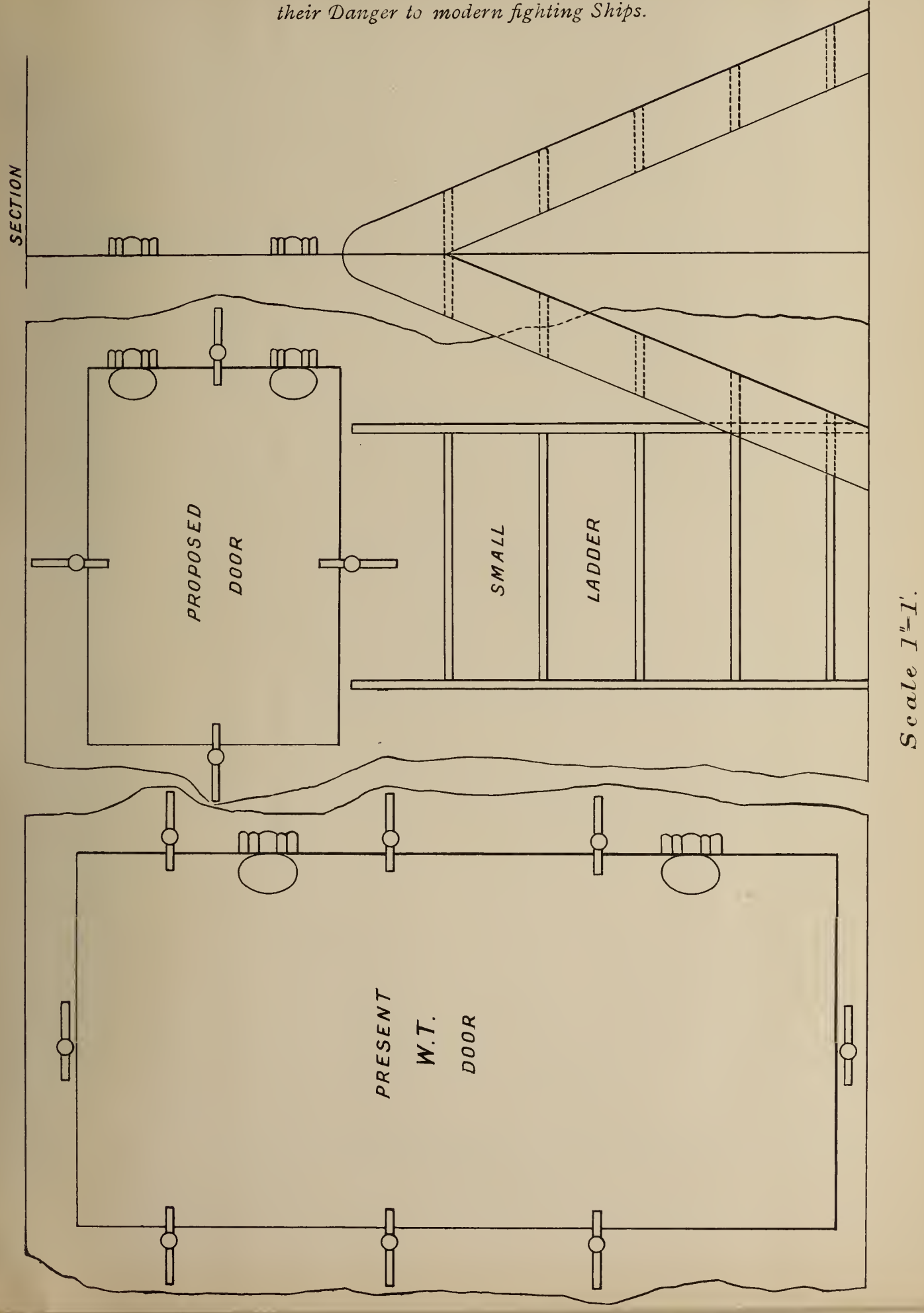


FIG. 5.

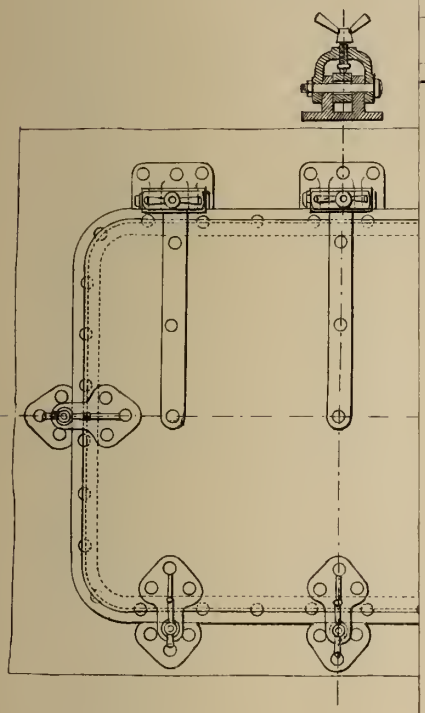
To Illustrate Captain the Right Hon. Lord Charles Beresford's Paper on Watertight Doors, and their Danger to modern fighting Ships.



ht Doors.

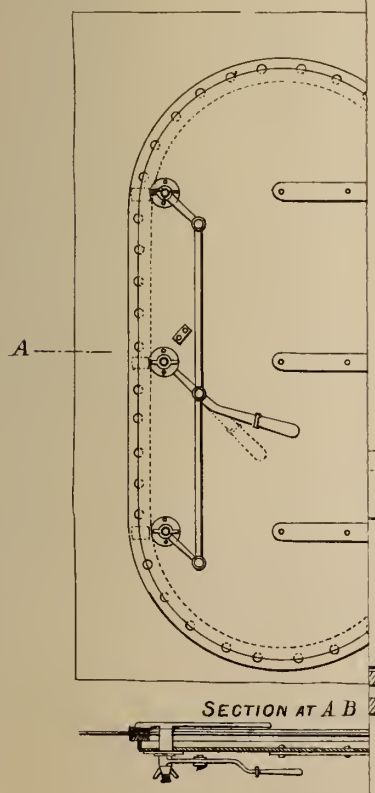
HINGED WATERTIGHT DOOR

FIG. 1



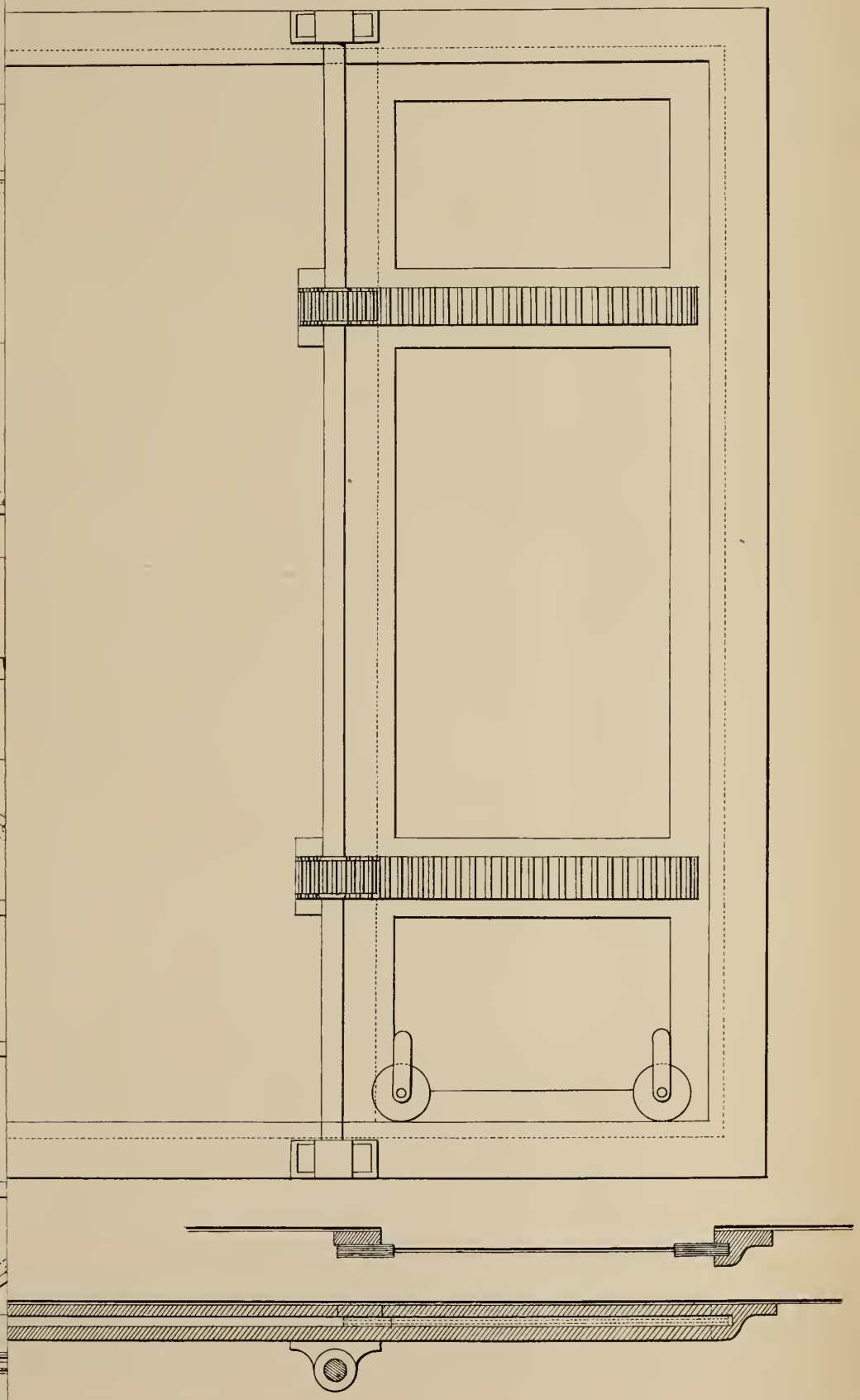
HINGED WATERTIGHT

FIG. 2



HORIZONTAL SLIDING WATERTIGHT DOOR SINGLE SEATED

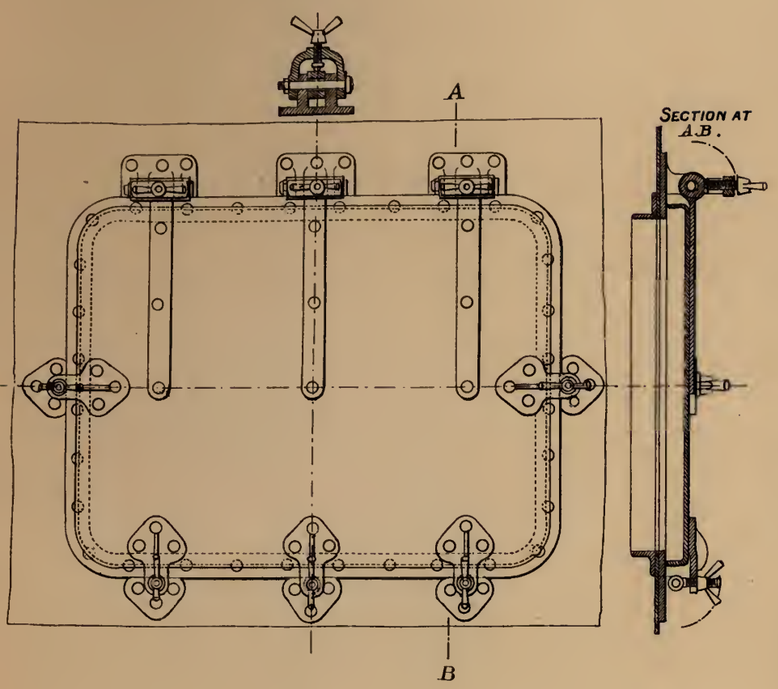
FIG. 4



To Illustrate Colonel N. Soliani's Paper on Watertight Doors.

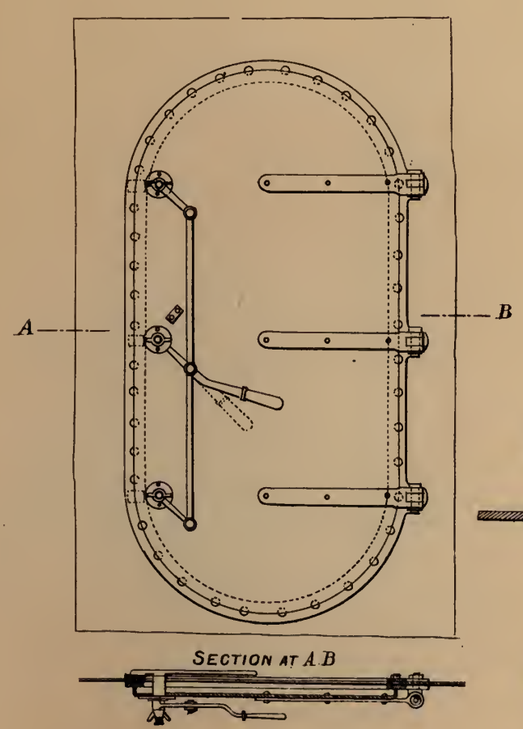
HINGED WATERTIGHT DOOR

FIG. 1



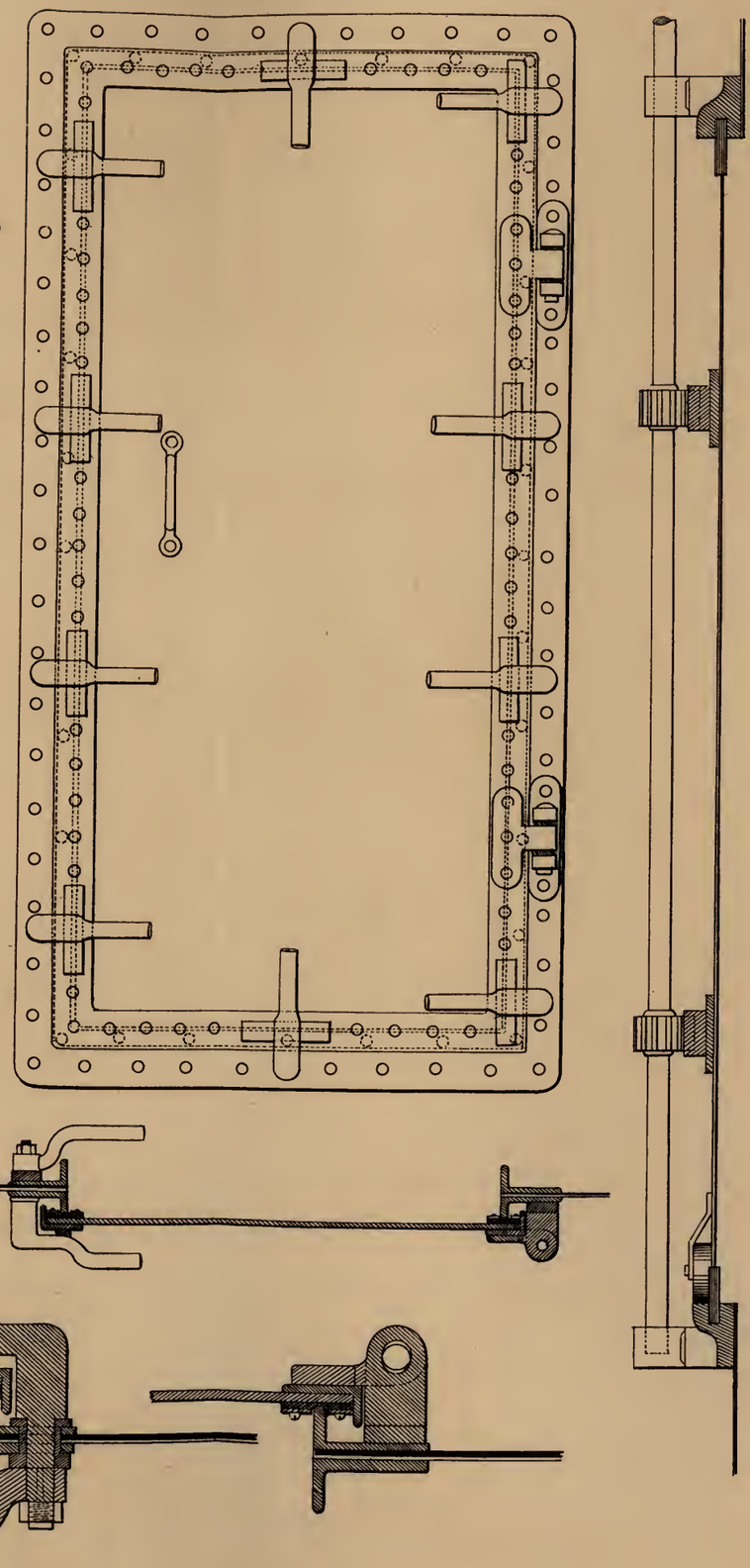
HINGED WATERTIGHT DOOR

FIG. 2



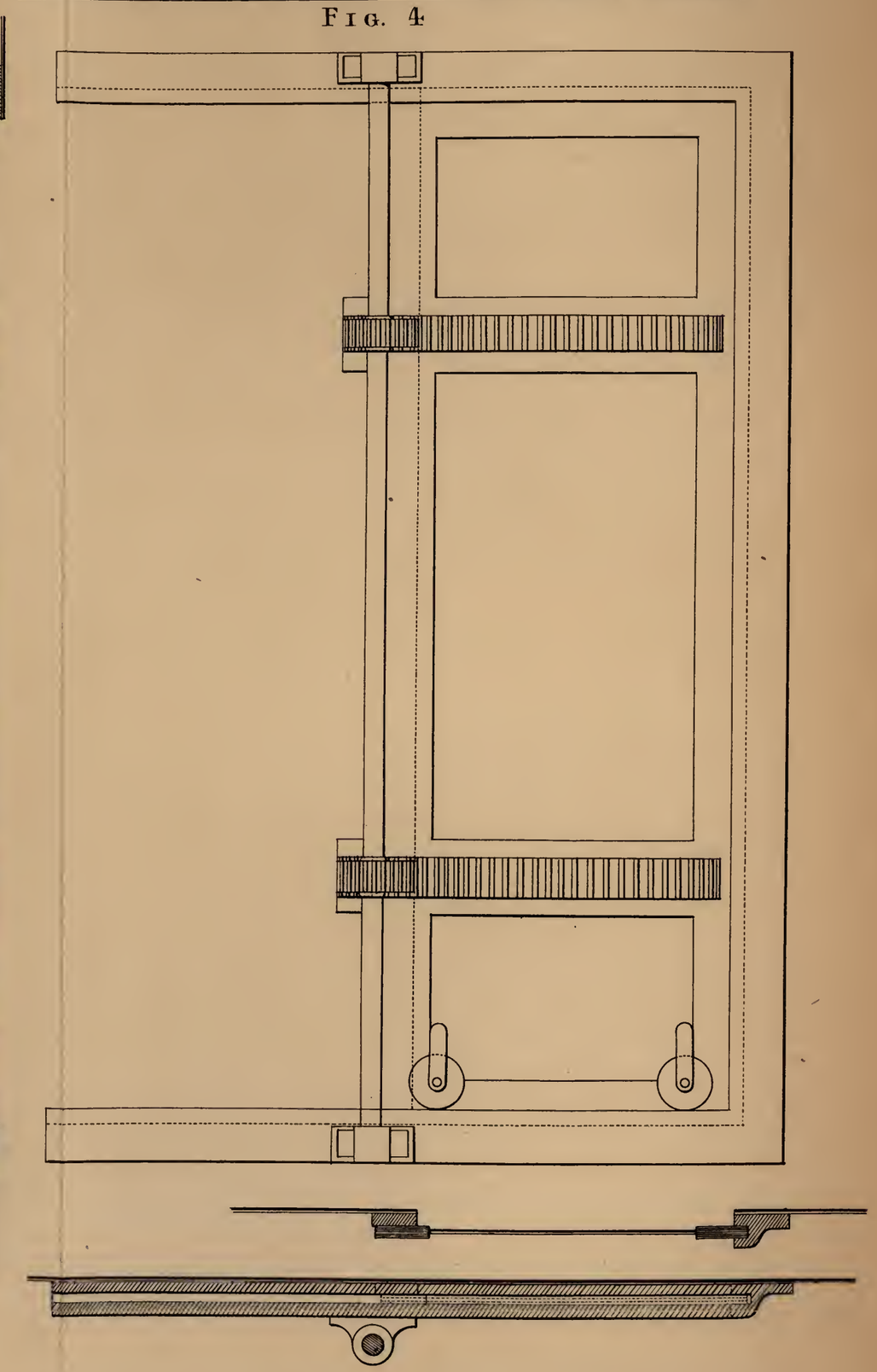
HINGED WATERTIGHT DOOR

FIG. 3



HORIZONTAL SLIDING WATERTIGHT DOOR SINGLE SEATED

FIG. 4

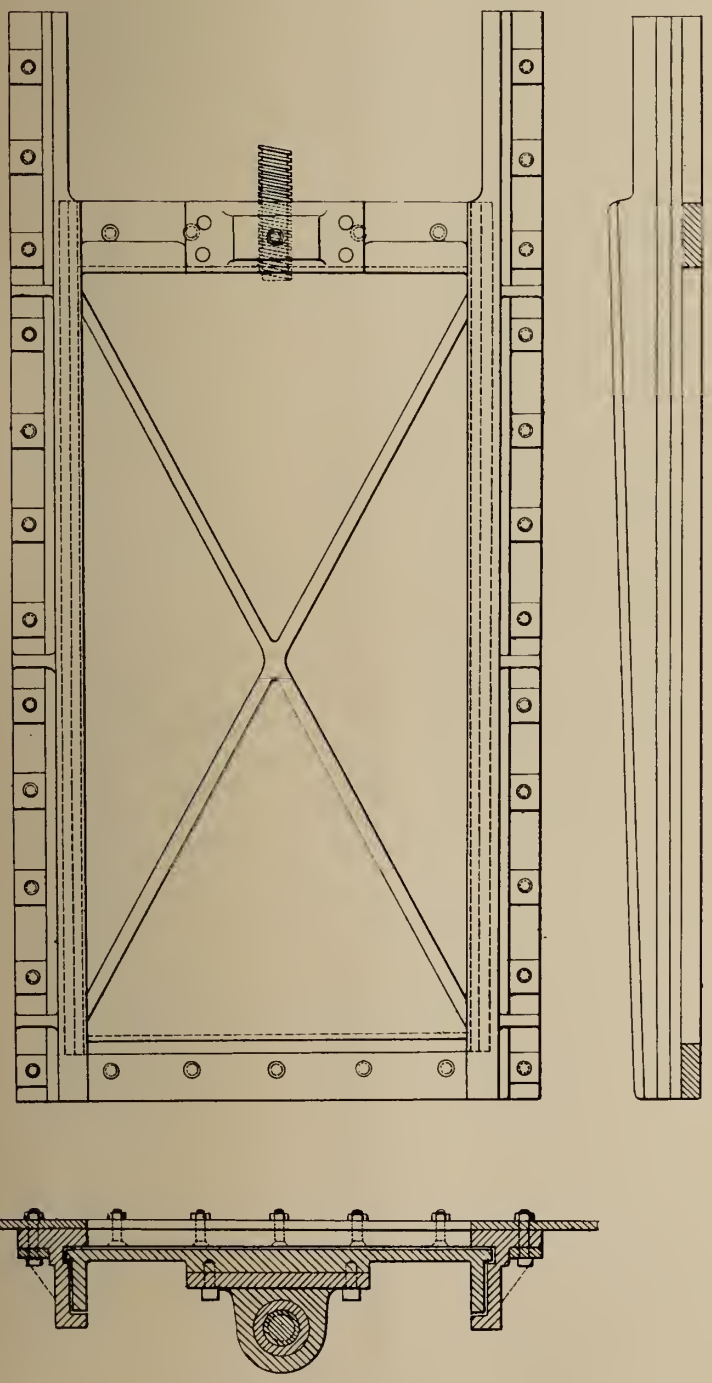


To Illustrate Colonel N. Soliani's Paper on Watertight Doors.

Bunker Vertical Sliding Watertight Door

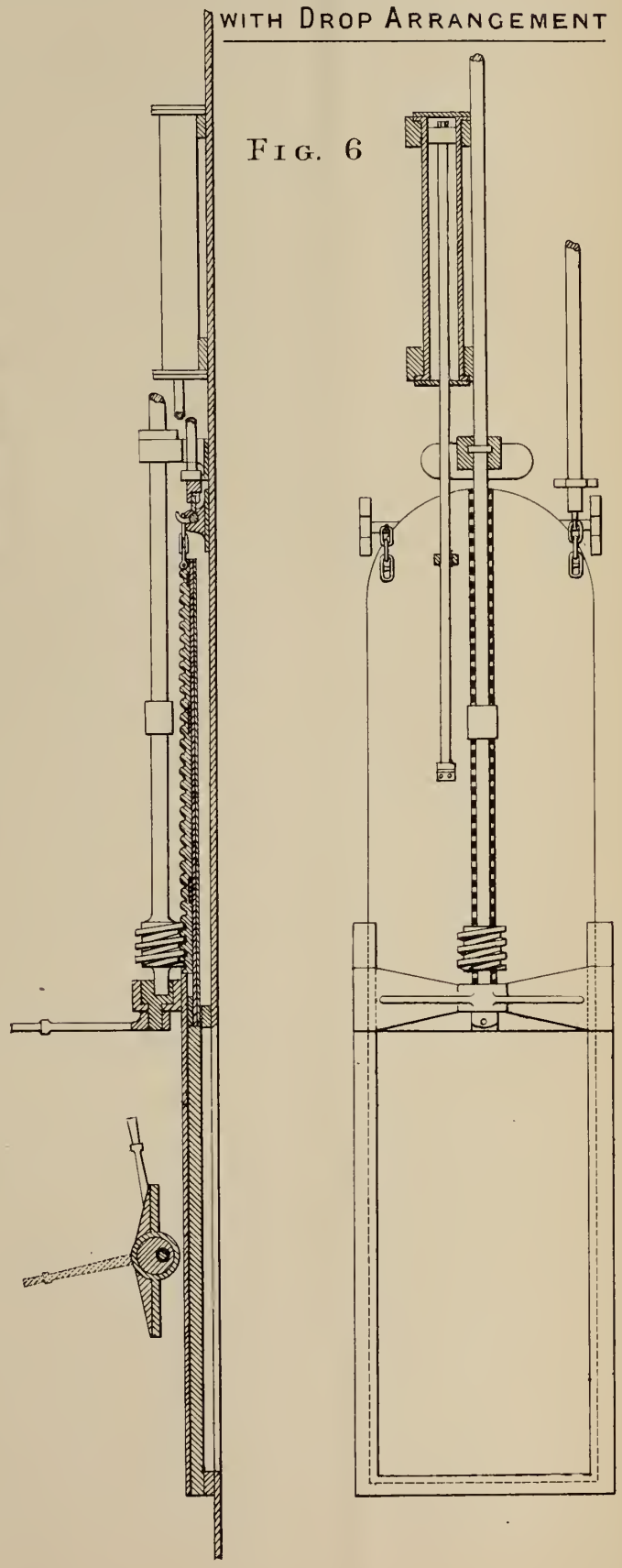
Single Seated

Fig. 5



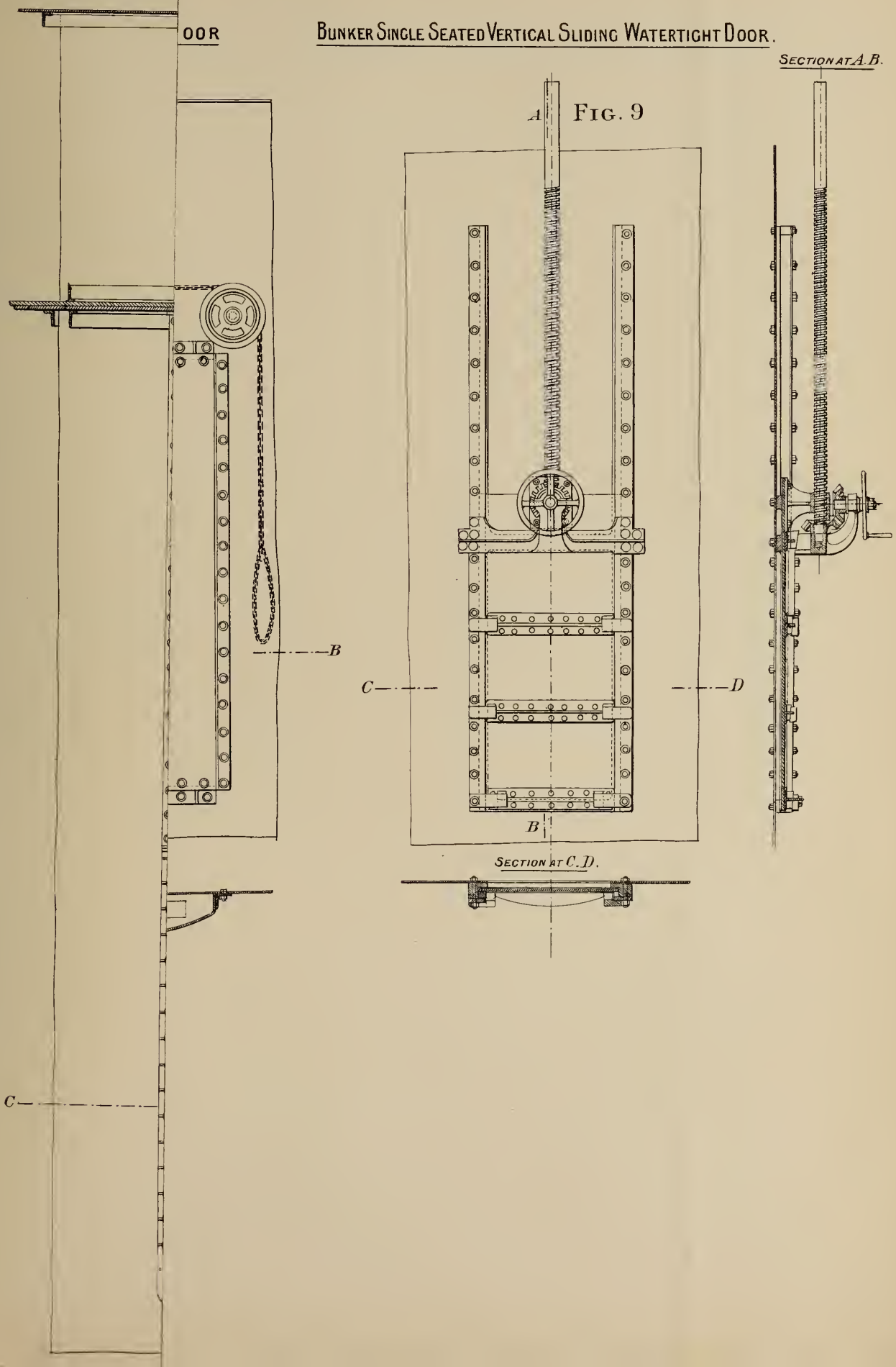
with Drop Arrangement

Fig. 6



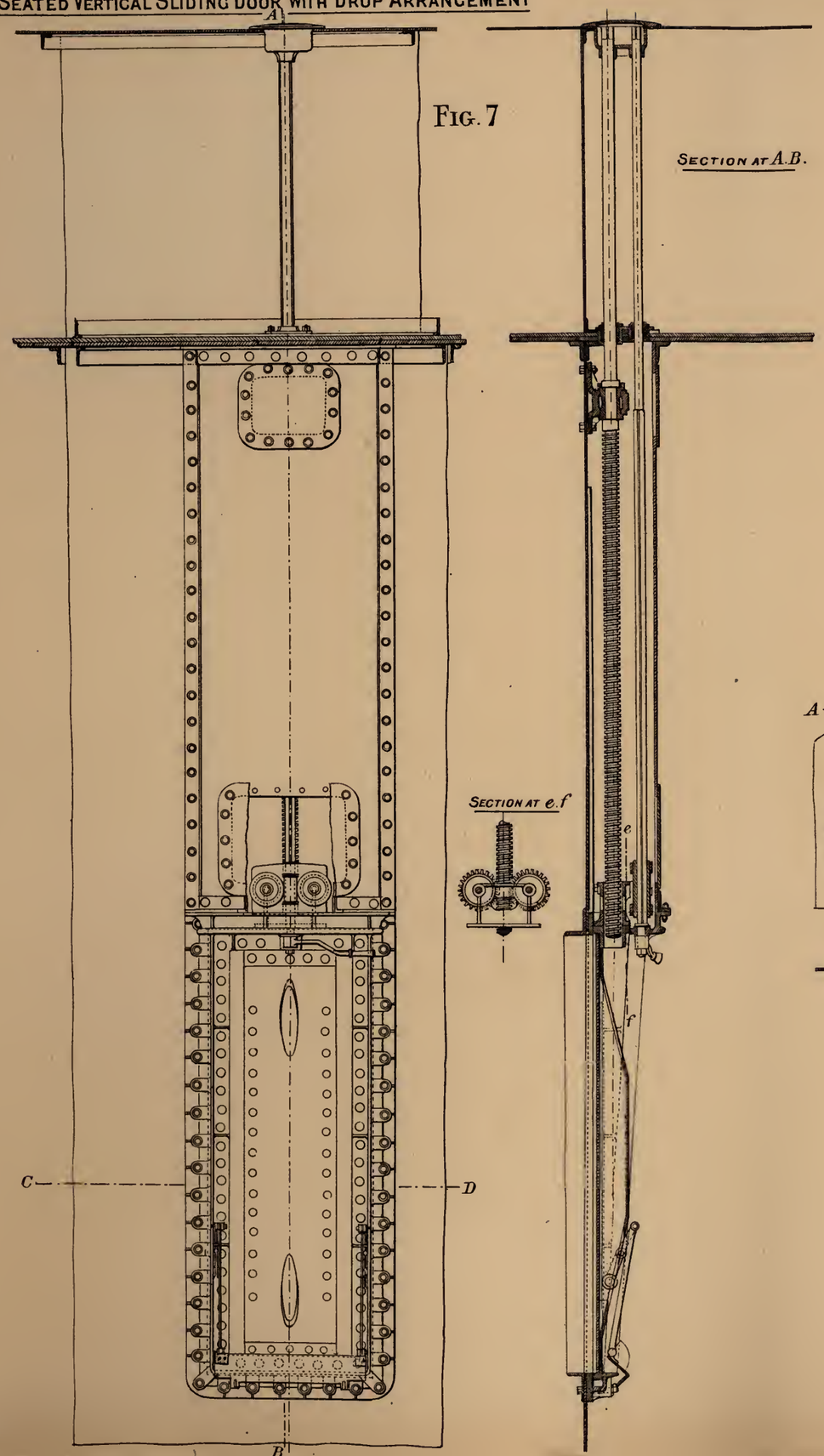
DOUBLE SEATED VERTICAL SLI OOR

BUNKER SINGLE SEATED VERTICAL SLIDING WATERTIGHT DOOR.

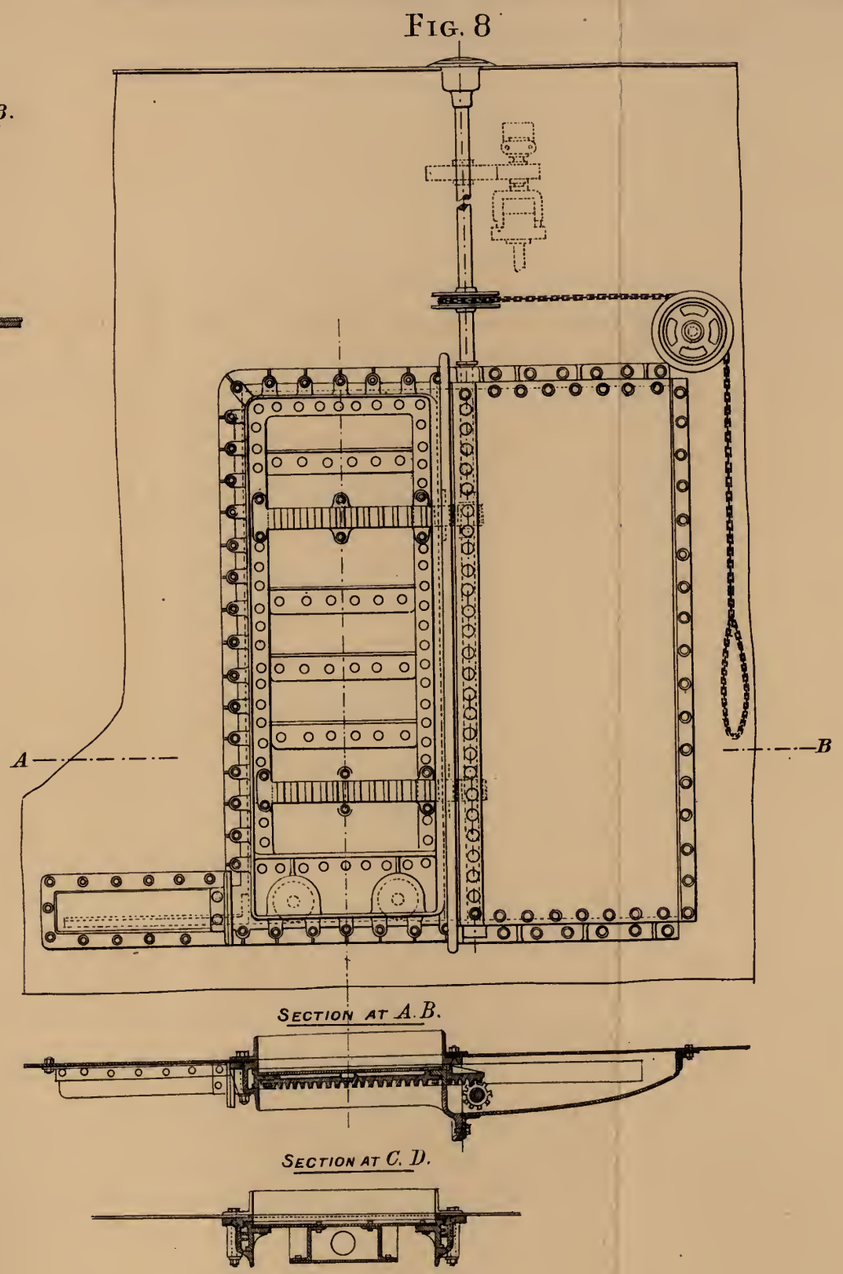


To Illustrate Colonel N. Soliani's Paper on Watertight Doors.

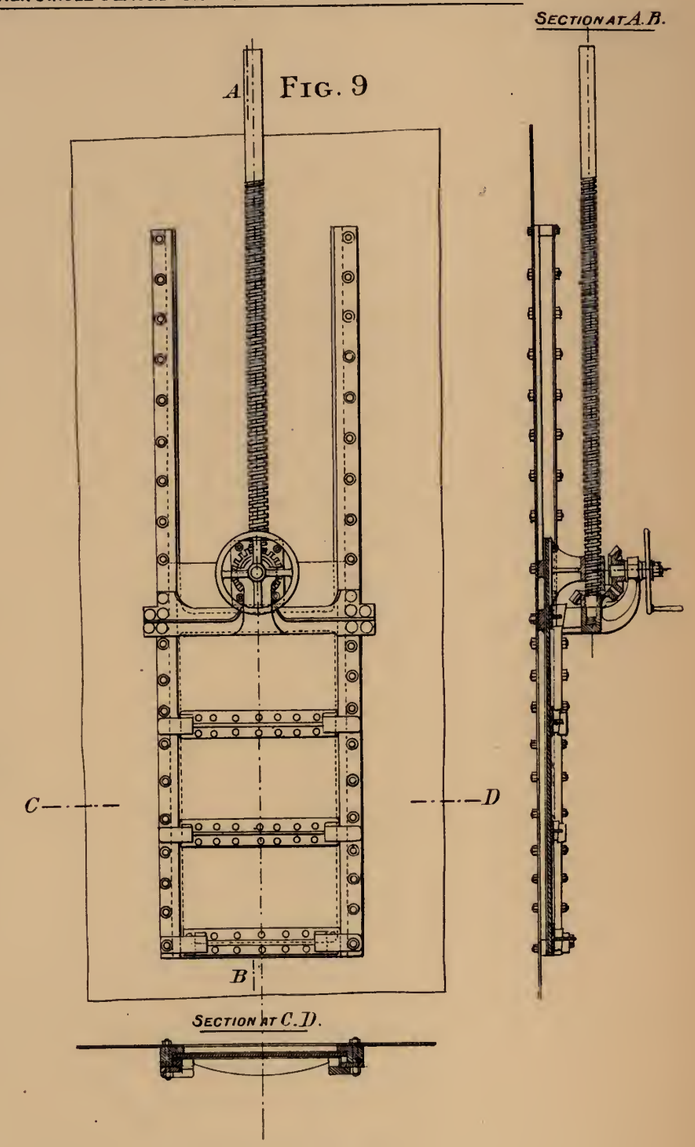
DOUBLE SEATED VERTICAL SLIDING DOOR WITH DROP ARRANGEMENT



DOUBLE SEATED HORIZONTAL SLIDING WATERTIGHT DOOR



BUNKER SINGLE SEATED VERTICAL SLIDING WATERTIGHT DOOR.



To Illustrate Colonel N. Soliani's Paper on Watertight Doors.

FIG. 10.

FIG. 11.

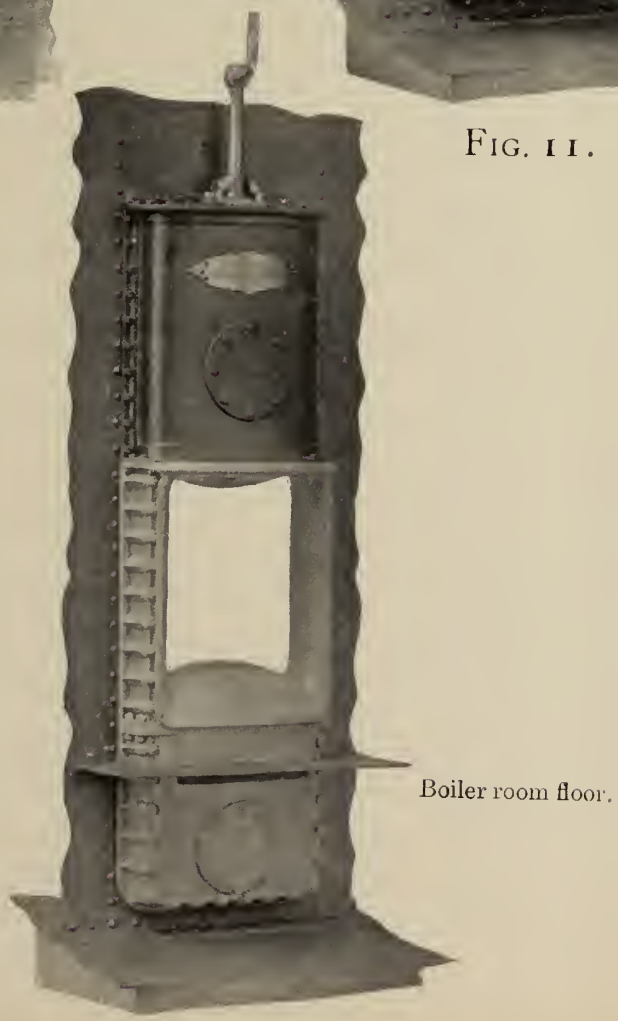


FIG. 12.

To Illustrate Mr. P. S. Pilcher's remarks on Captain the Right Hon. Lord Charles Beresford's Paper on Watertight Doors, and their Danger to Modern fighting Ships, and Colonel N. Soliani's Paper on Watertight Doors.

Fig. 1.

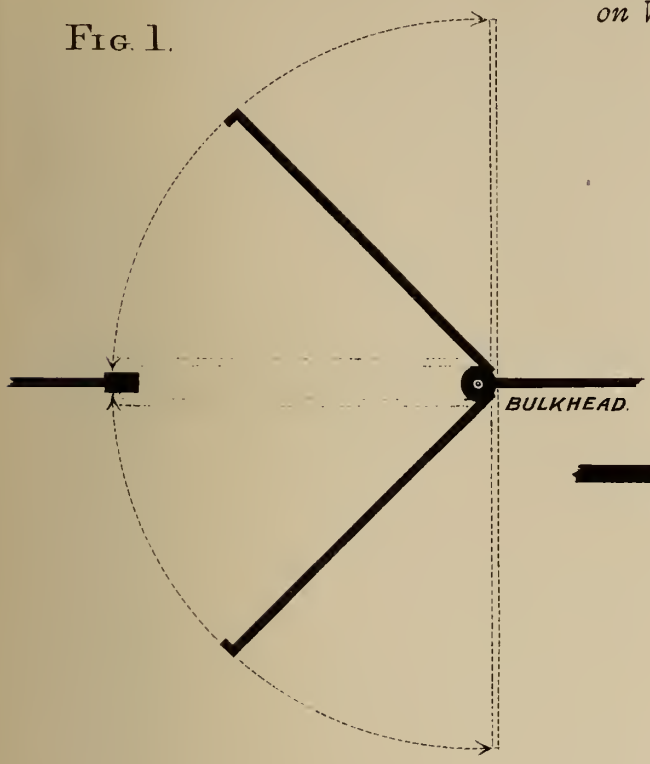


Fig. 2.

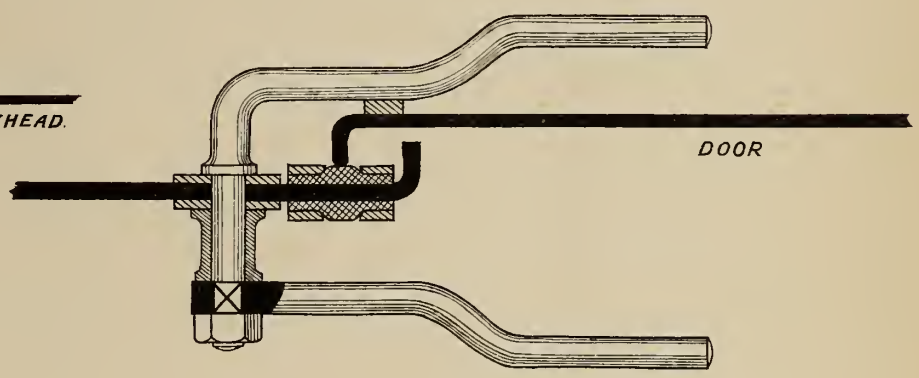


Fig. 3.

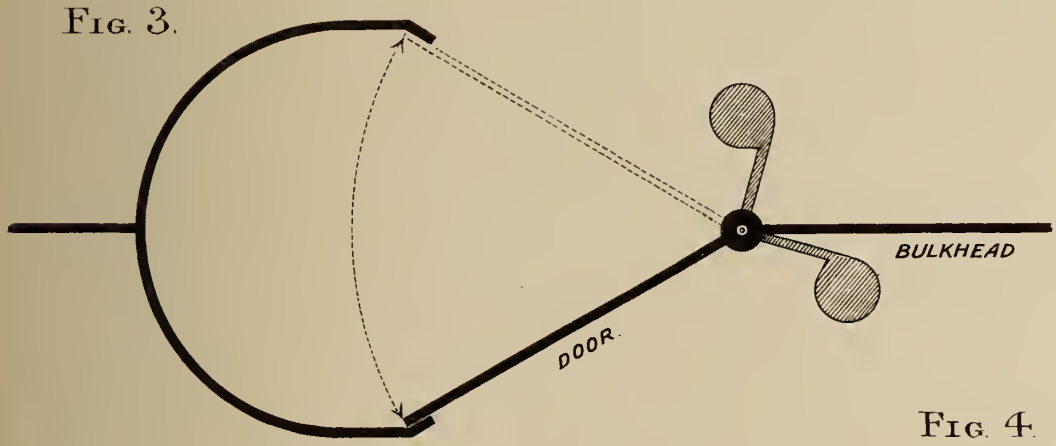
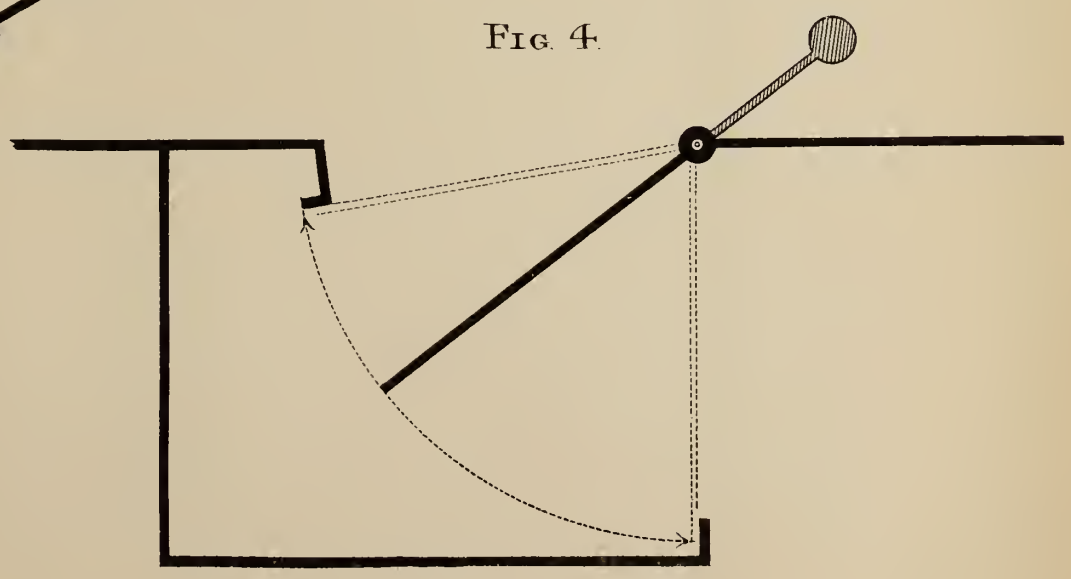


Fig. 4.



To Illustrate Mr. J. Bruhn's Paper on Some Geometry in Connection with the Stability of Ships.

FIG. 1.

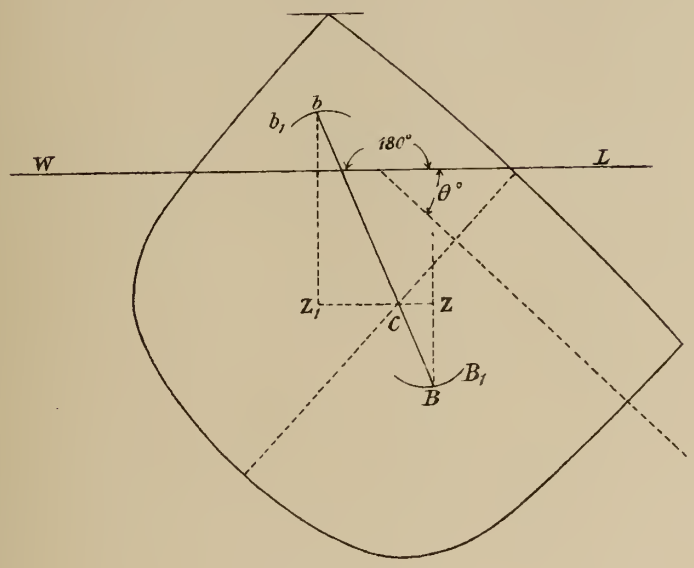


FIG. 2.

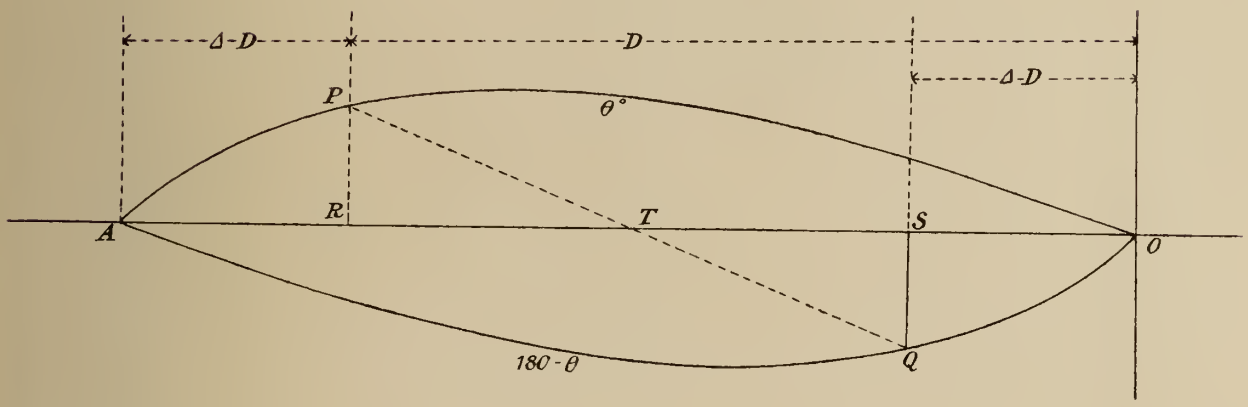
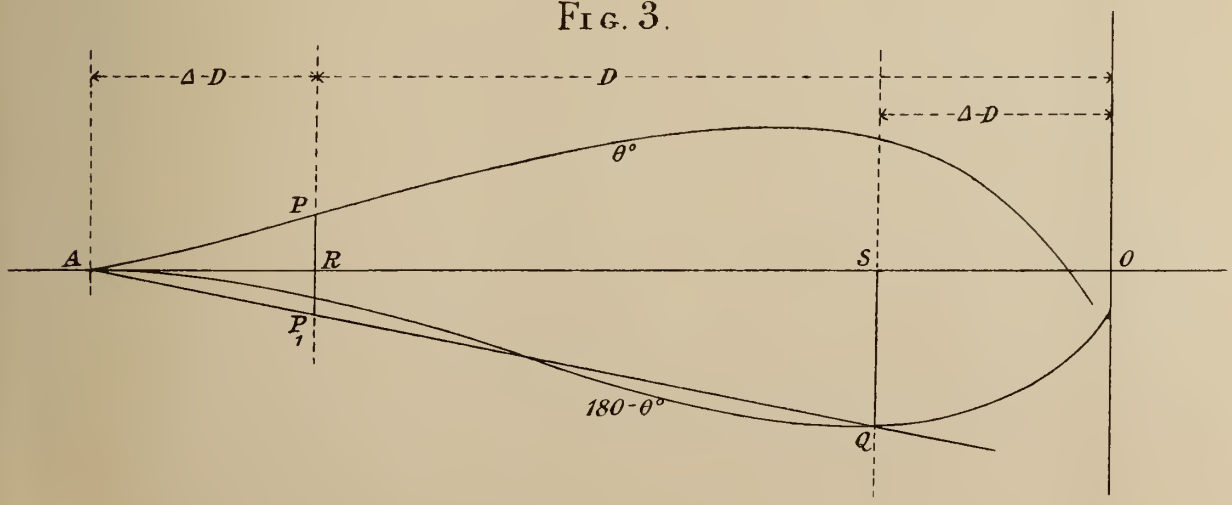


FIG. 3.



To Illustrate Mr. J. Bruhn's Paper on Some Geometry in Connection with the Stability of Ships.

FIG. 4.

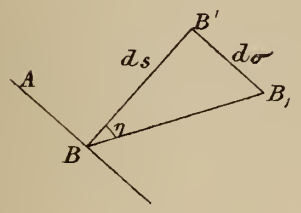


FIG. 5.

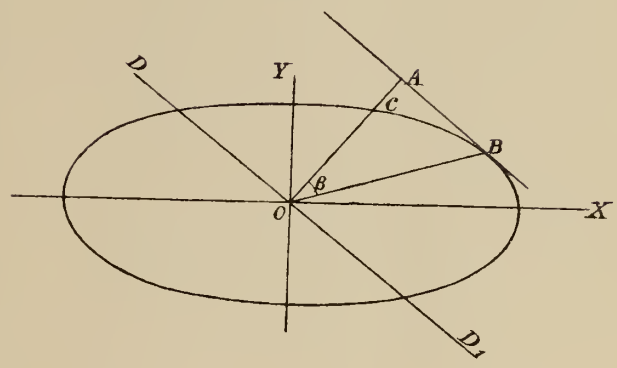


FIG. 6.

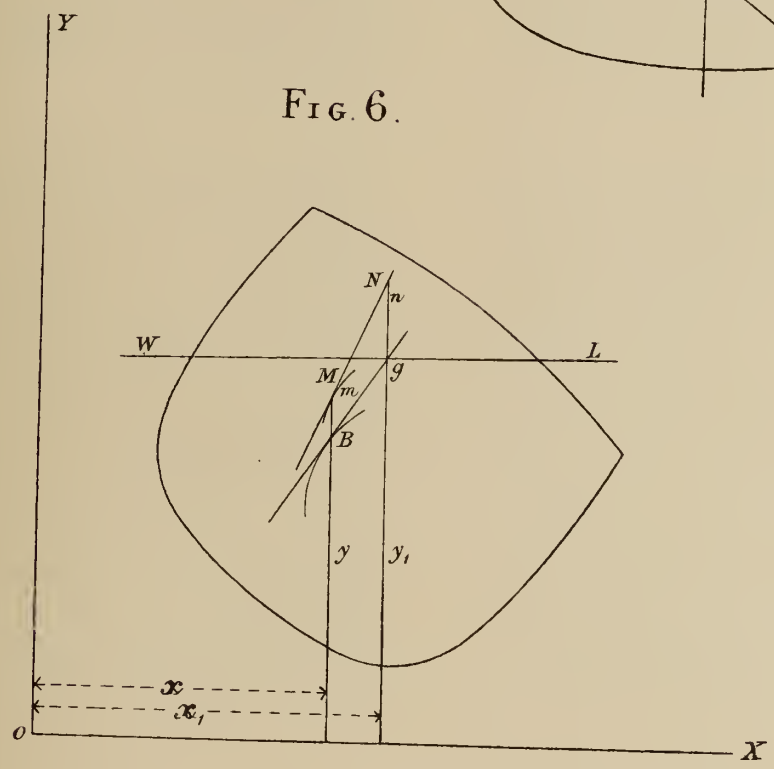


FIG. 7.

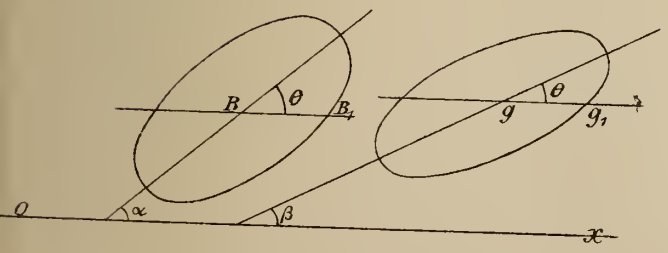
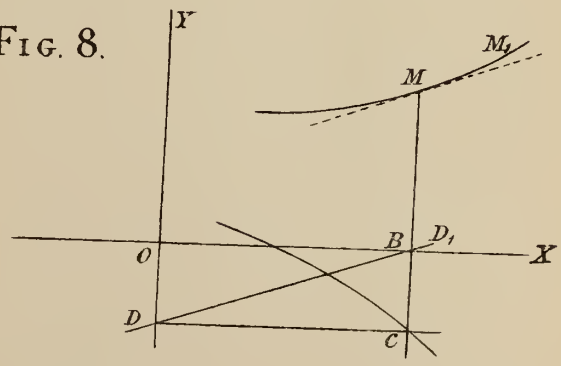


FIG. 8.



To Illustrate Mr. A. E. Seaton's Paper on the Causes of mysterious Fractures in the Steel used by Marine Engineers, as revealed by the Microscope.

Fig. 2. Section C. Magnified about 23 diameters. Direct light.

Fig. 3. Section C. Magnified about 170 diameters. Direct light.

Fig. 4. Section A. Magnified about 170 diameters. Direct light.

Fig. 5. Section C. Magnified about 170 diameters. Direct light.

Fig. 6. Section C. Magnified about 170 diameters. Direct light.

Fig. 7. Section C Magnified about 170 diameters. Direct light.

To Illustrate Mr. A. E. Seaton's Paper on the Causes of mysterious Fractures in the Steel used by Marine Engineers, as revealed by the Microscope.

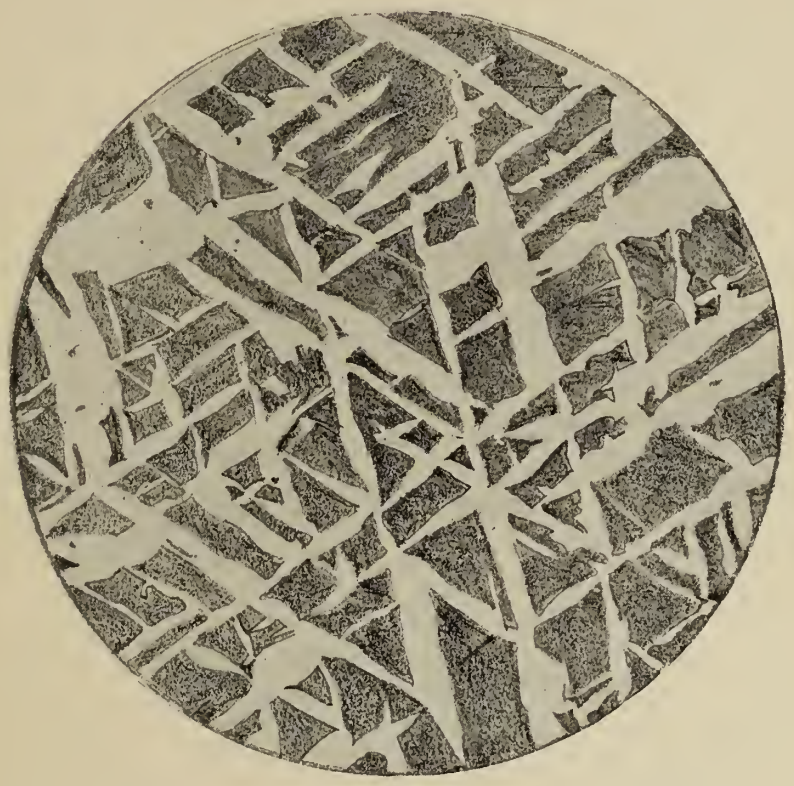


Fig. 8. Section of a Steel Casting, imperfectly Annealed. Magnified 100 diameters

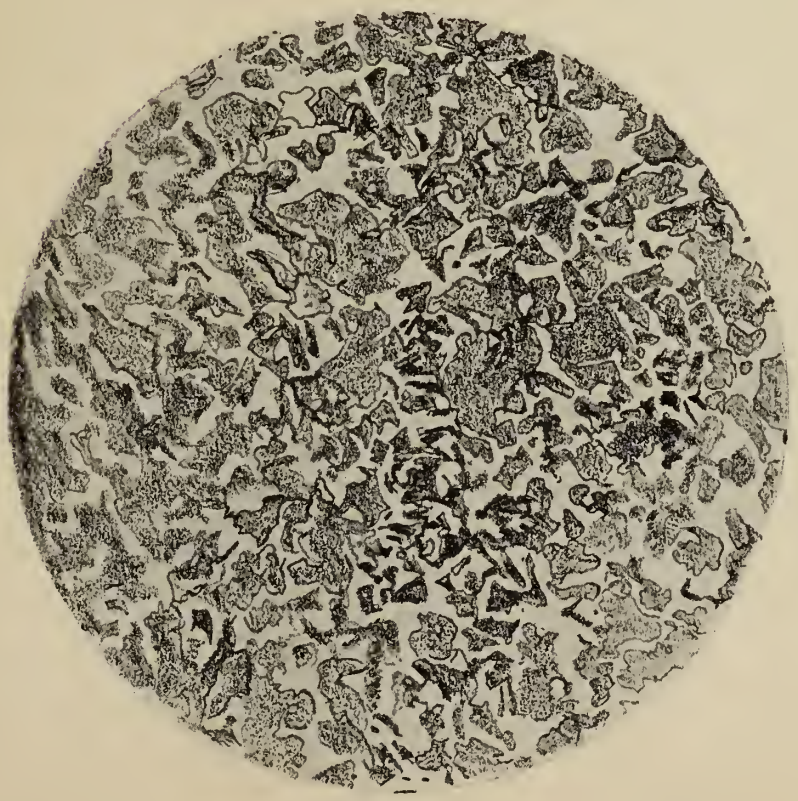


Fig. 9. Section of the same Casting after being Perfectly Annealed. Magnified 100 diameters.

To Illustrate Mr. A. E. Seaton's Paper on the Causes of mysterious Fractures in the Steel used by Marine Engineers, as revealed by the Microscope.

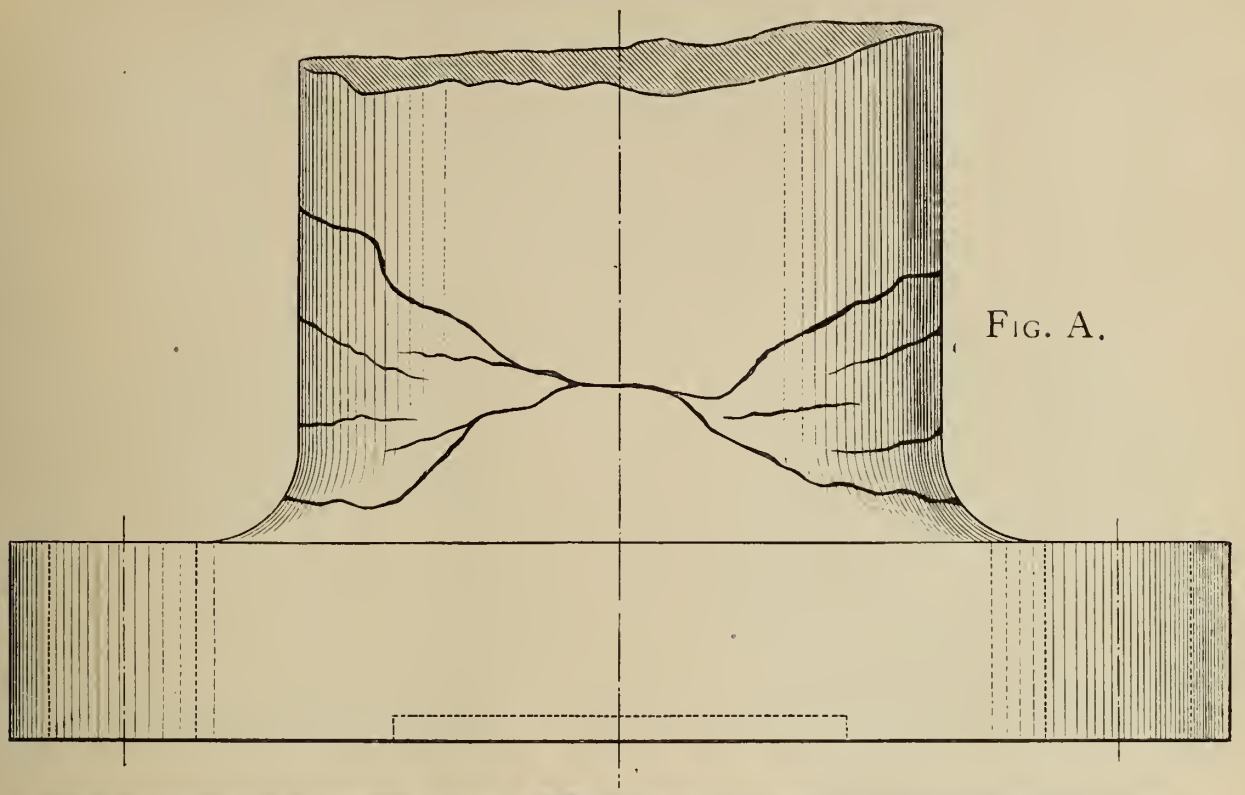


Fig. A.

Fig. B.

To Illustrate Mr. C. E. Ellis' remarks on Mr. A. E. Seaton's Paper on the Causes of mysterious Fractures in the Steel used by Marine Engineers as revealed by the Microscope.

Fig. 1. High Sulphur. Longitudinal Section. Magnified 45 Diameters.

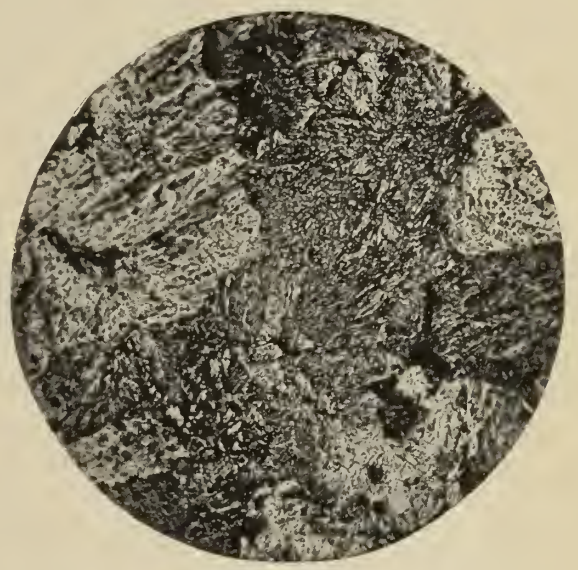


Fig. 2. High Sulphur. Transverse Section. Magnified 120 Diameters.

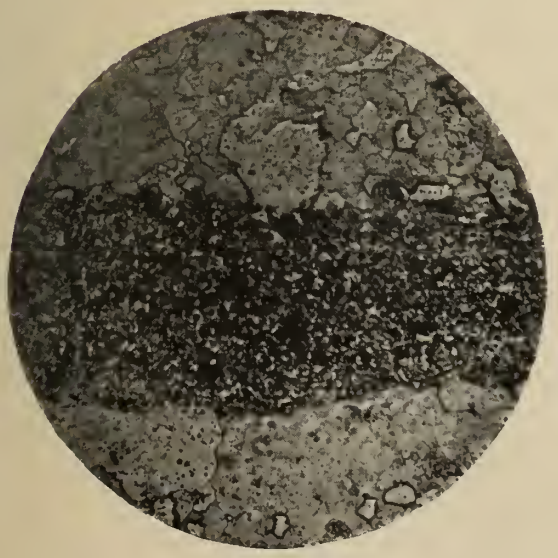


Fig. 3. High Sulphur. Transverse Section. Magnified 45 Diameters.

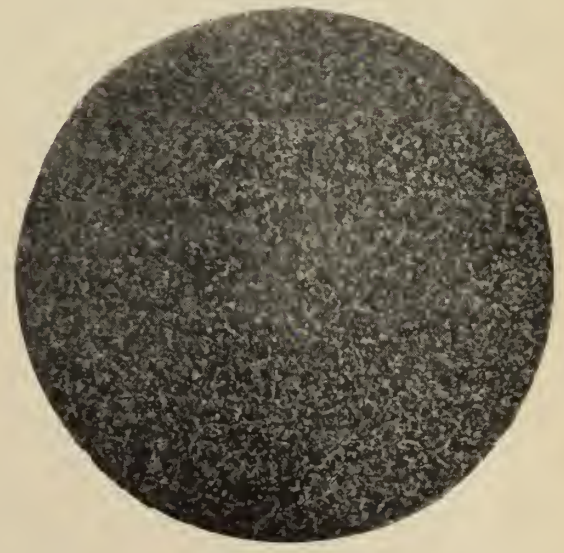


Fig. 4. Ordinary Good Steel. Sulphur, ·02; Phosphor, ·03 Magnified 45 Diameters.

Trans.

To Illustrate Mr. C. E. Stromever's Paper on the Measurement of Feed and Circulating Water, &c by chemical Means.

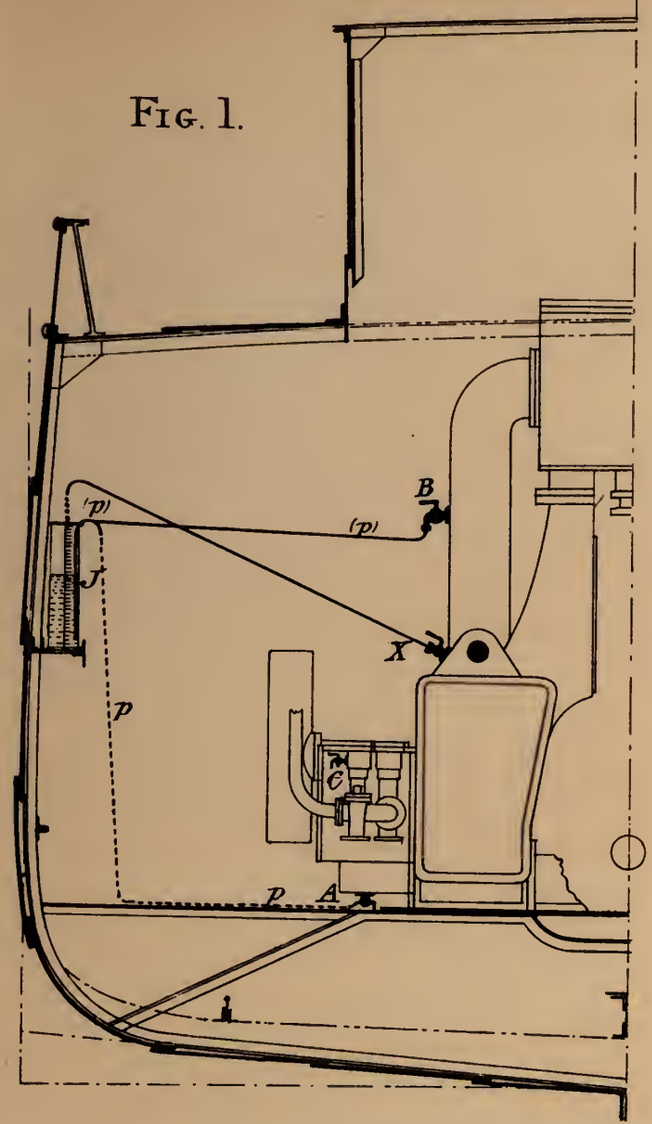


Fig. 1.

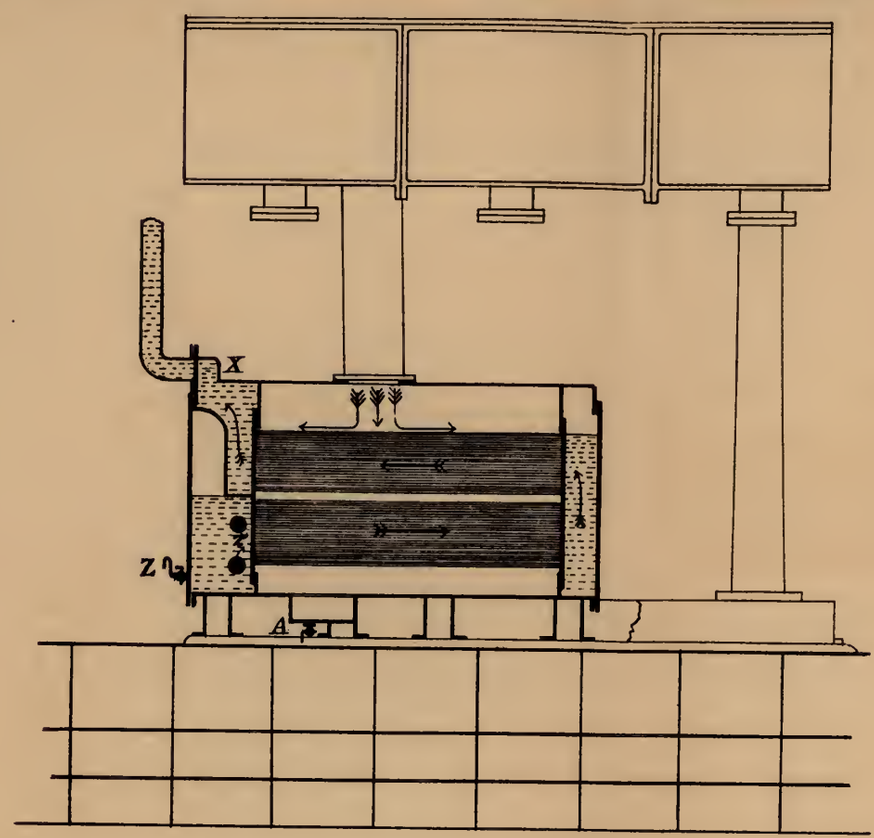


Fig. 2

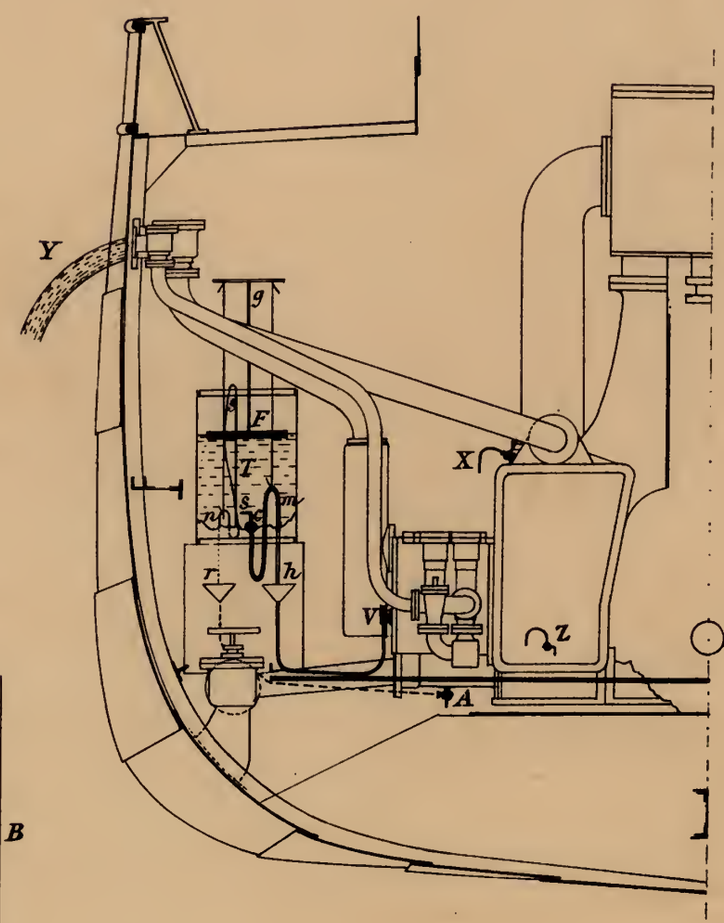


Fig. 3.

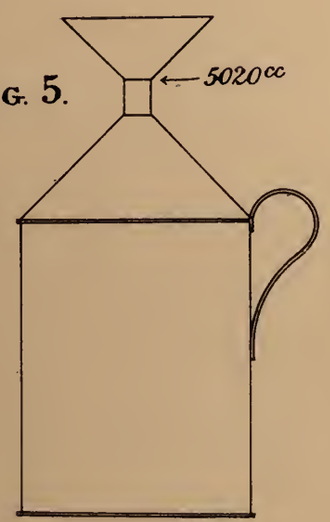


Fig. 5.

Fig. 4.

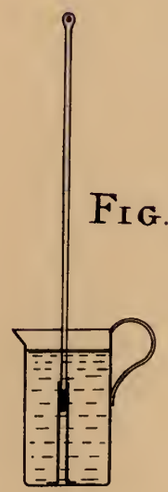


Fig. 6.

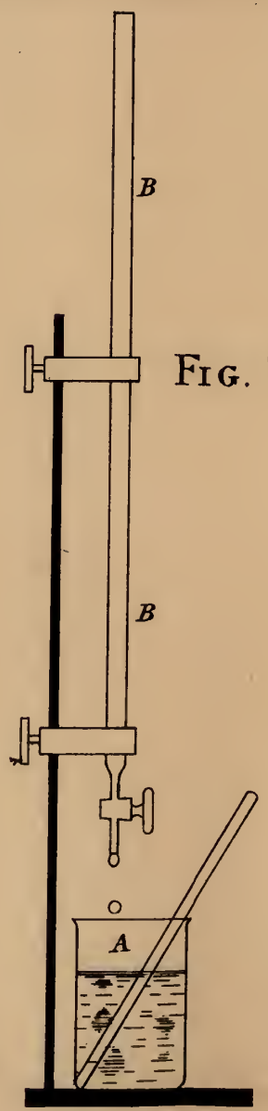


Fig. 7.

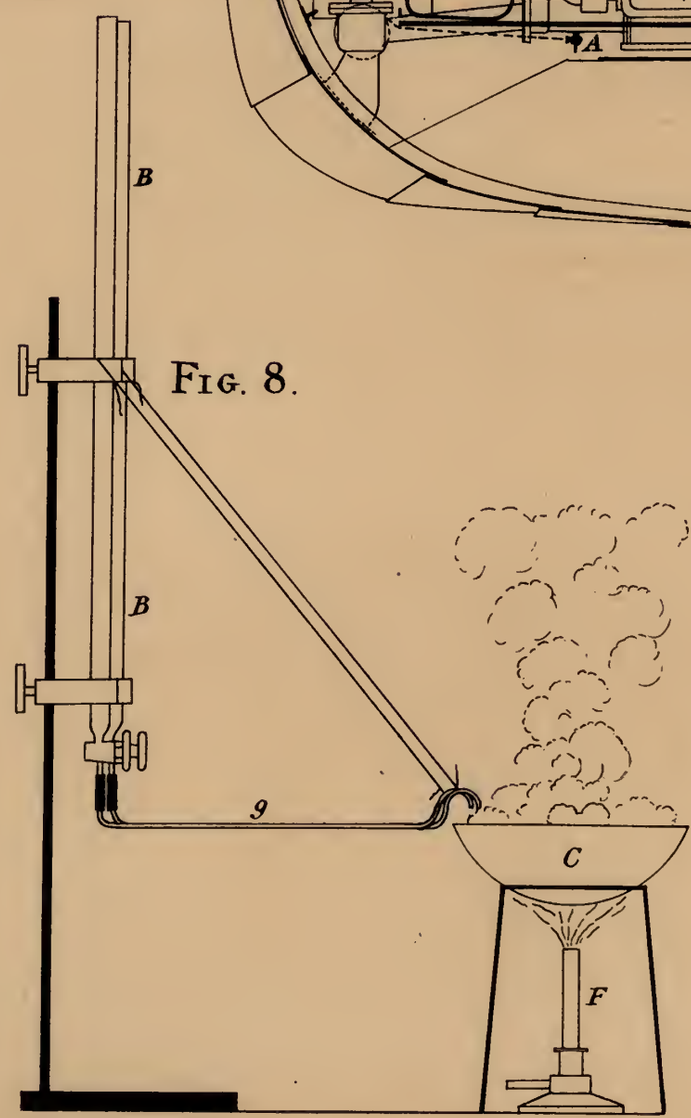
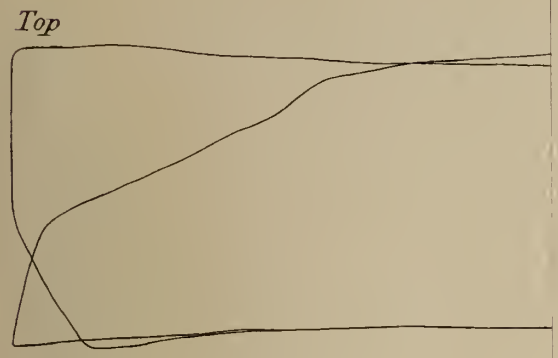


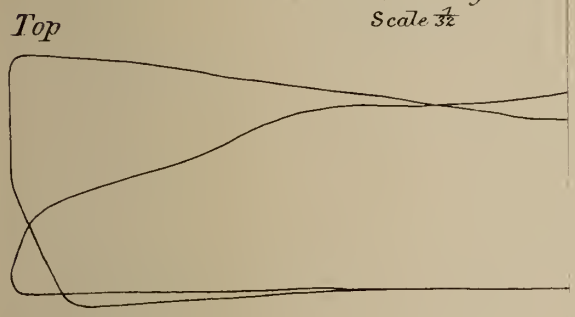
Fig. 8.

To Illustrate Mr. C. E. Stromeyer

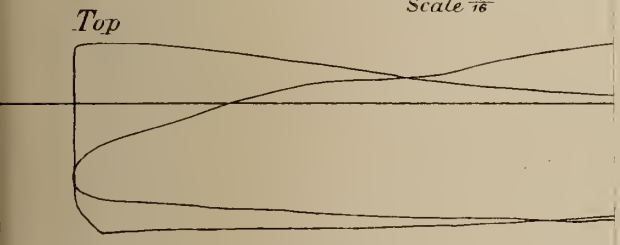
High Pressure Cylinder.
Scale $\frac{1}{64}$



Mean Pressure Cylinder.
Scale $\frac{1}{32}$



Low Pressure Cylinder.
Scale $\frac{1}{16}$

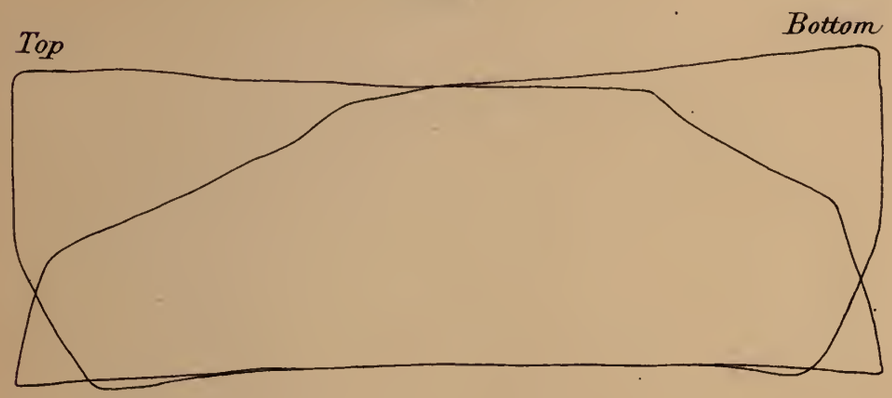


To Illustrate Mr. C. E. Stromeyer's Paper on the Measurement of Feed and Circulating Water, &c., by chemical Means.

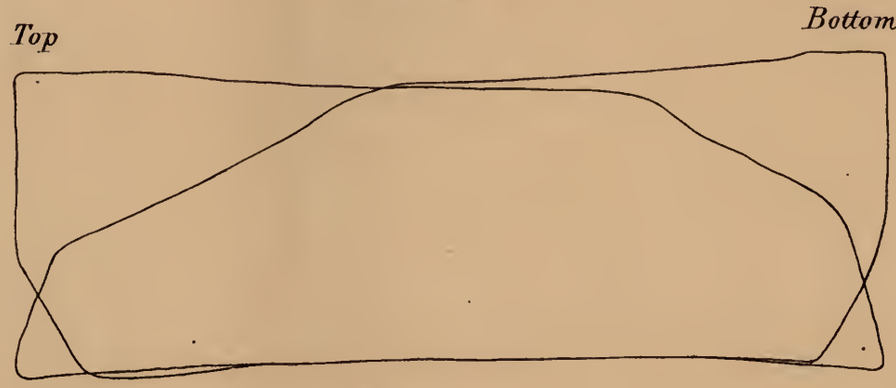
INDICATOR CARDS.

Engine D. Table IX.

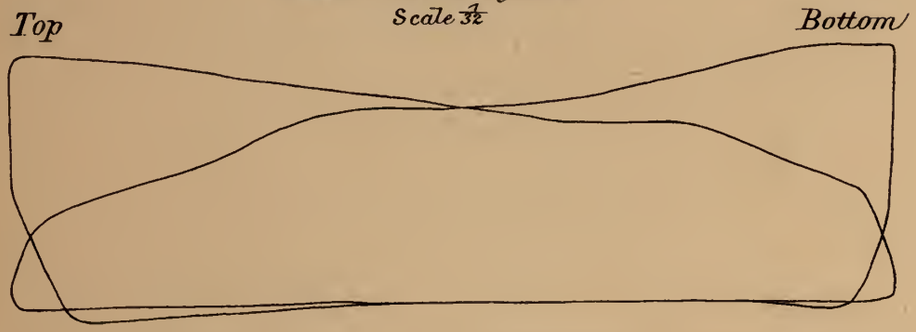
High Pressure Cylinder.
Scale $\frac{1}{64}$



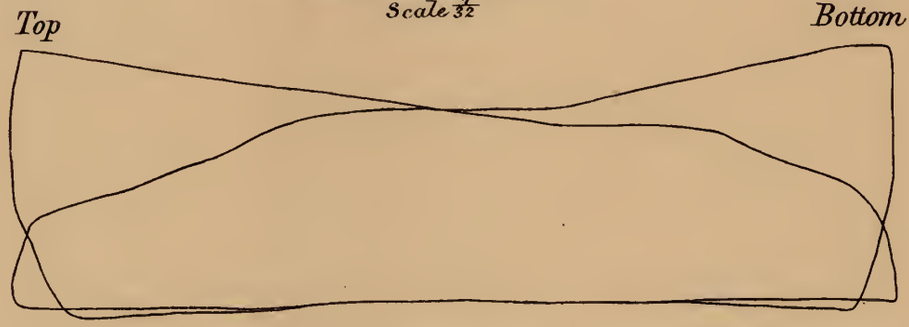
High Pressure Cylinder.
Scale $\frac{1}{64}$



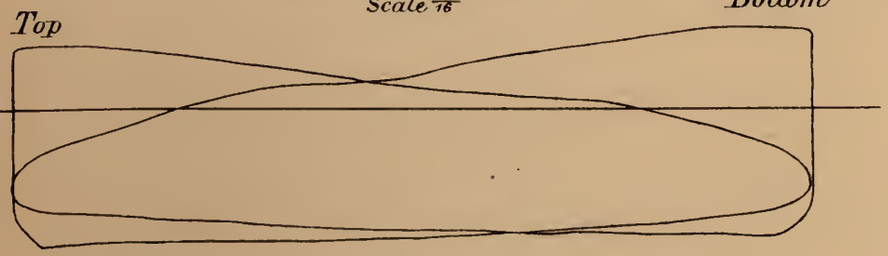
Mean Pressure Cylinder.
Scale $\frac{1}{32}$



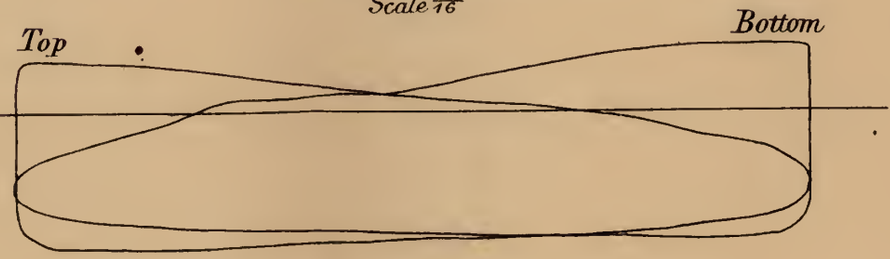
Mean Pressure Cylinder.
Scale $\frac{1}{32}$



Low Pressure Cylinder.
Scale $\frac{1}{16}$



Low Pressure Cylinder.
Scale $\frac{1}{16}$

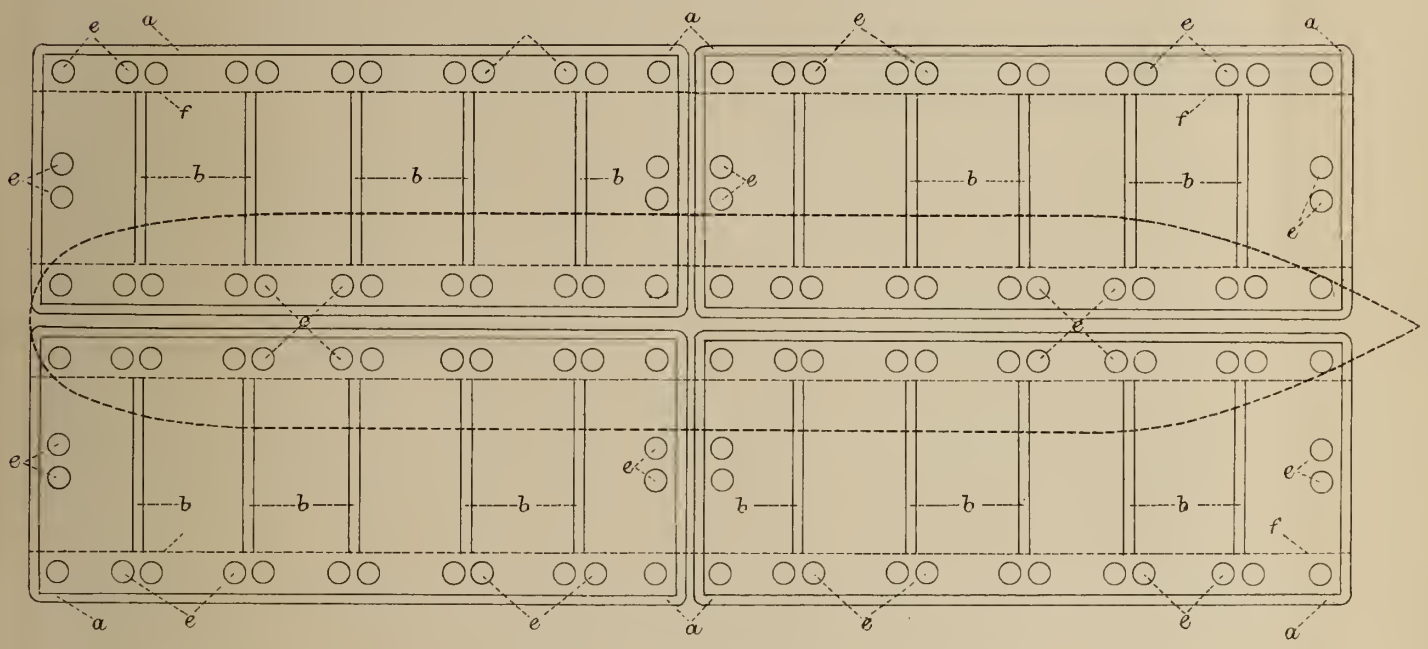


To Illustrate Mr. J. G. Kinghorn's Paper on Salvage Appliances.

View Shewing Four Camels in Position over Wreck

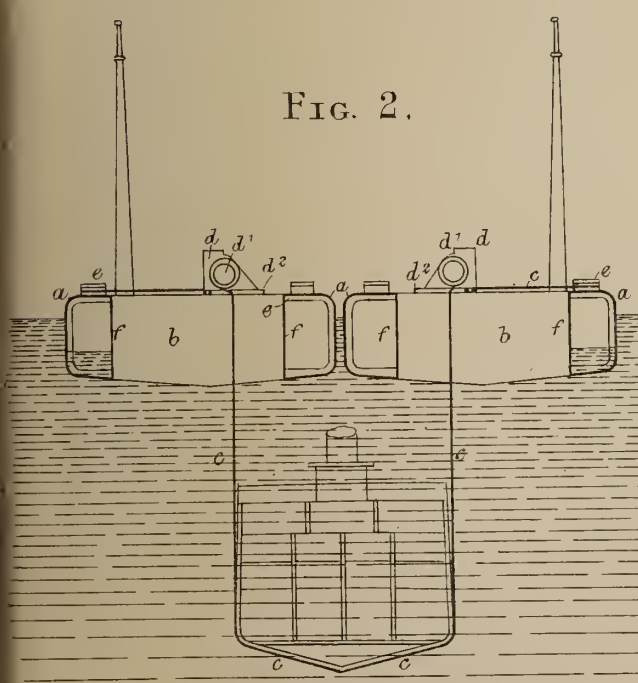
Wreck Shewn under by Dotted Lines

Fig. 1



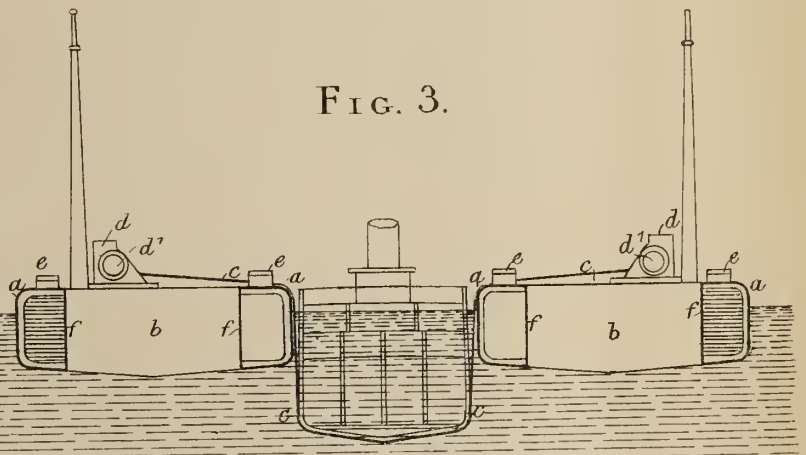
Cross Section Shewing Vessels Slung ready Lifting with Wire Ropes Leading Through Wells in Camels

Fig. 2.



Section Shewing Vessel being Lifted with Wire Ropes over Sides of Camels

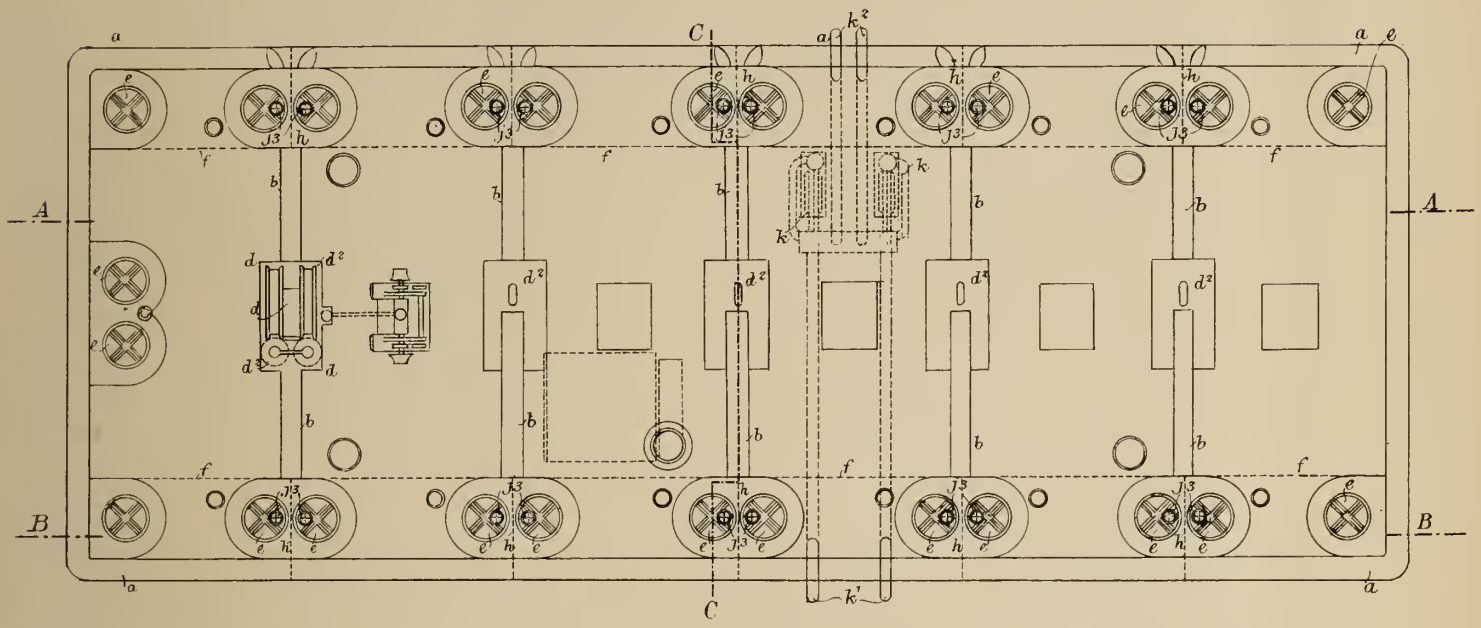
Fig. 3.



To Illustrate Mr. J. G. Kinghorn's Paper on Salvage Appliances.

DECK PLAN OF CAMEL

FIG. 4



FIGS. 5 & 6, LONGITUDINAL SECTIONS OF CAMEL, AT LINES AA AND BB FIG. 4.
FIG. 7. CROSS SECTION AT LINE CC FIG. 4.

FIG. 5.

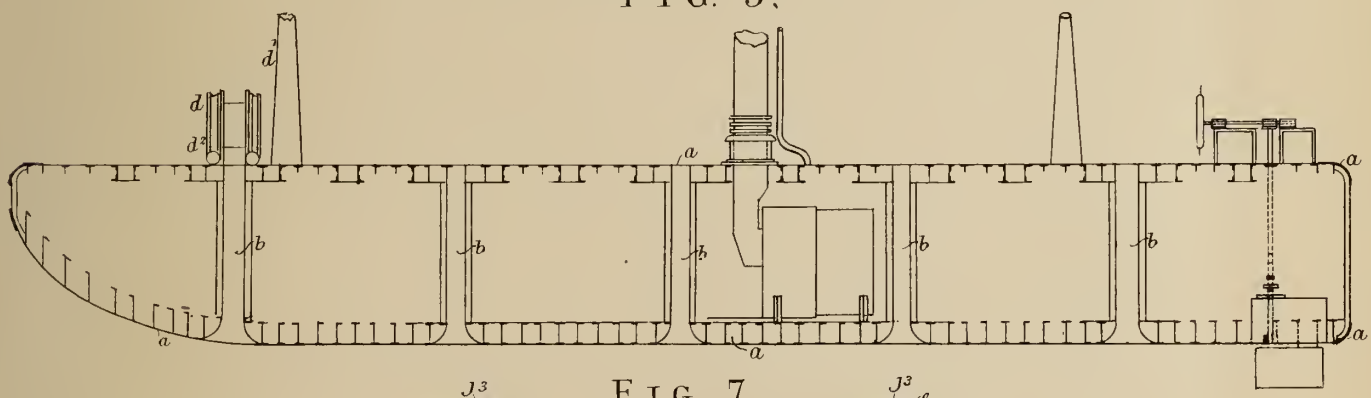


FIG. 7.

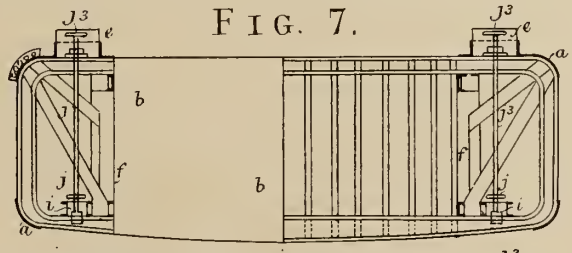
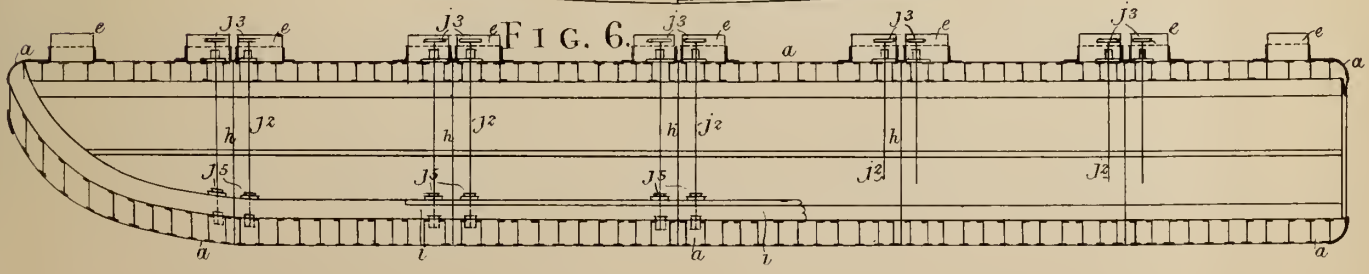
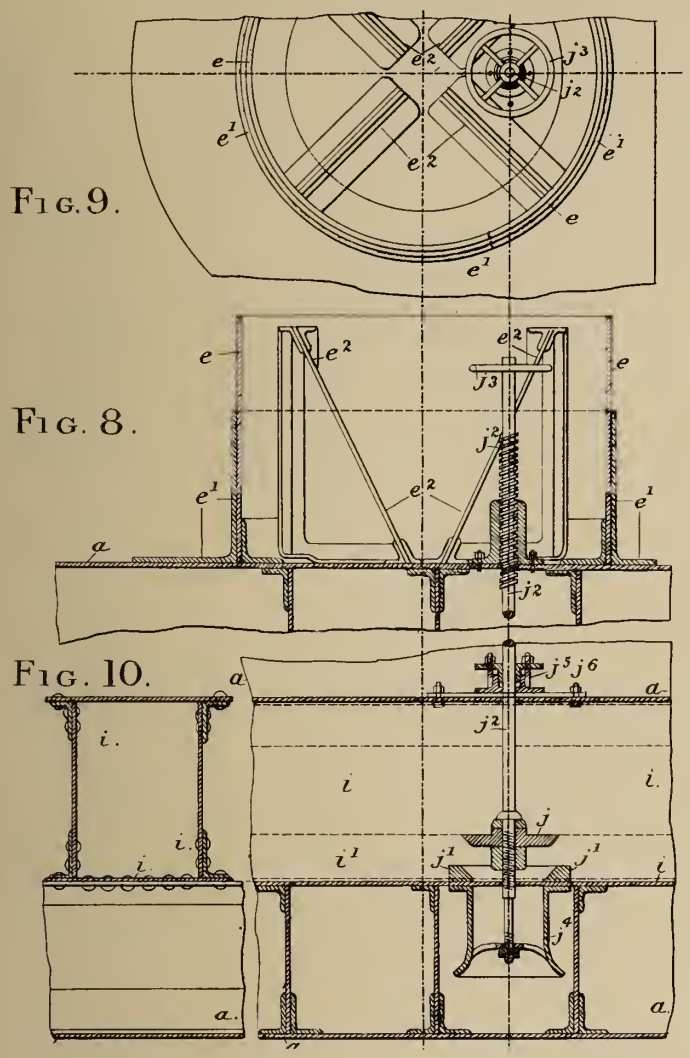


FIG. 6.

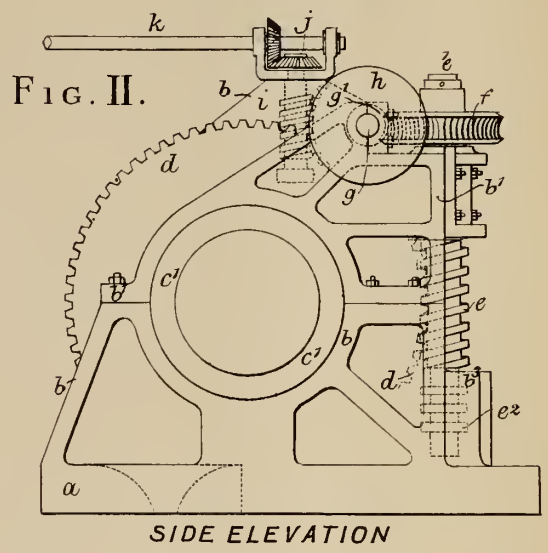


To Illustrate Mr. J. G. Kinghorn's Paper on Salvage Appliances.

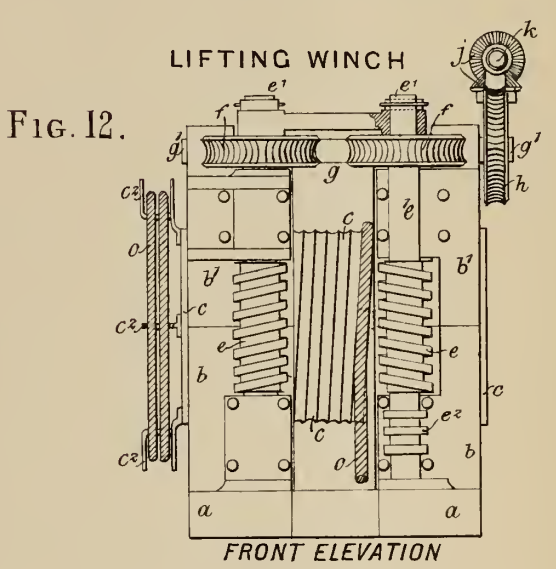
PLAN AND SECTION OF BOLLARD KELSON AND VALVES



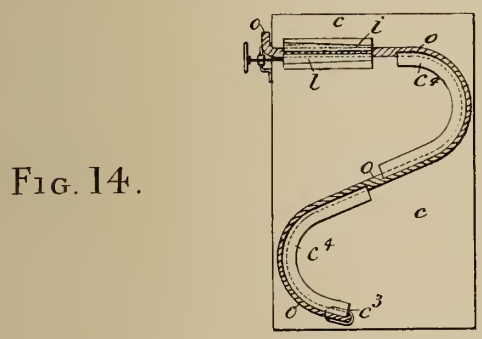
LIFTING WINCH



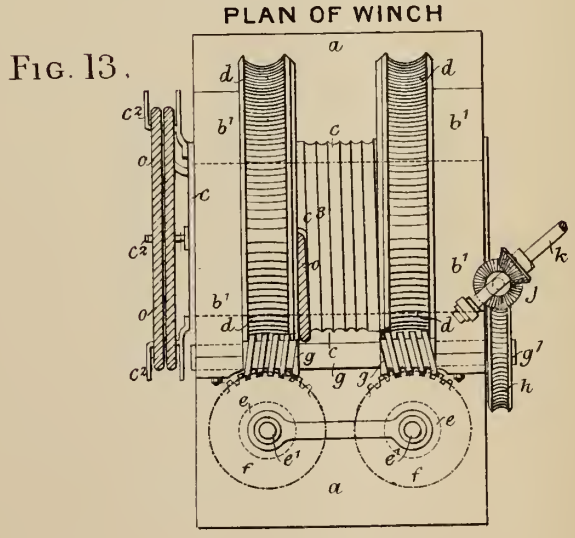
LIFTING WINCH



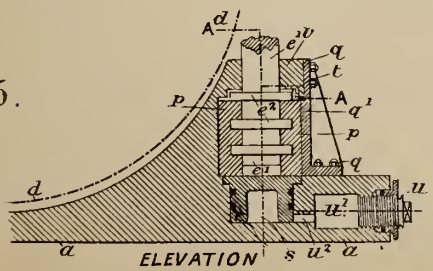
VIEW OF INTERIOR BARREL OF THE WINCH OPENED OUT FLAT



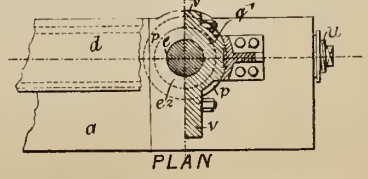
PLAN OF WINCH



HYDRAULIC THRUST BEARING



HYDRAULIC THRUST BEARING

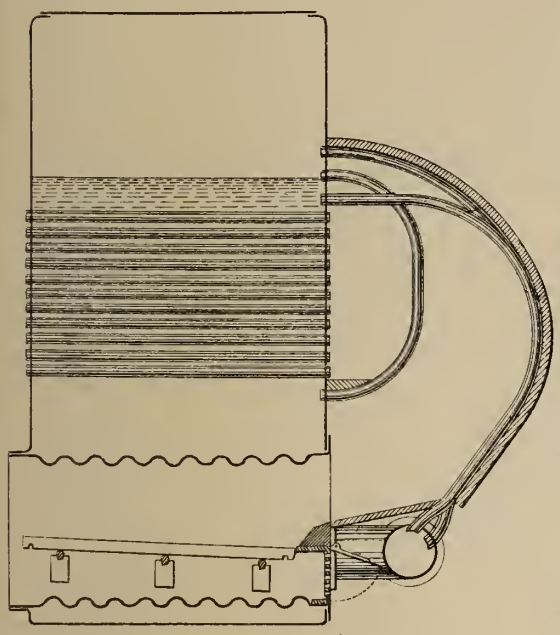


To Illustrate Colonel N. Soliani's Paper on compound Marine Boilers.

COMPOUND MARINE CYLINDRICAL BOILER

WITH COMBUSTION CHAMBER BUILT UP WITH WATER TUBES.

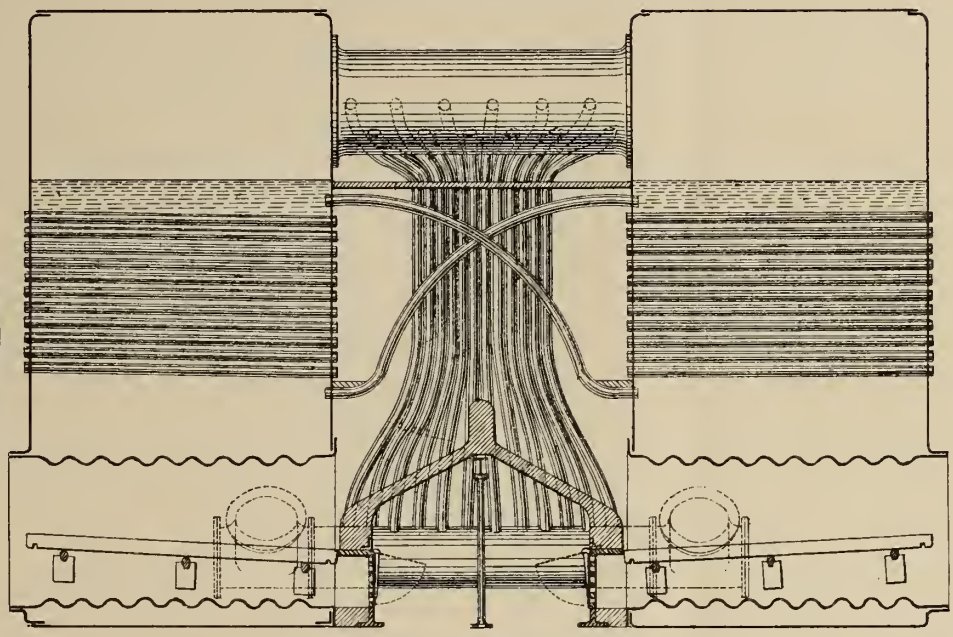
SINGLE ENDED



LONGITUDINAL VERTICAL SECTION

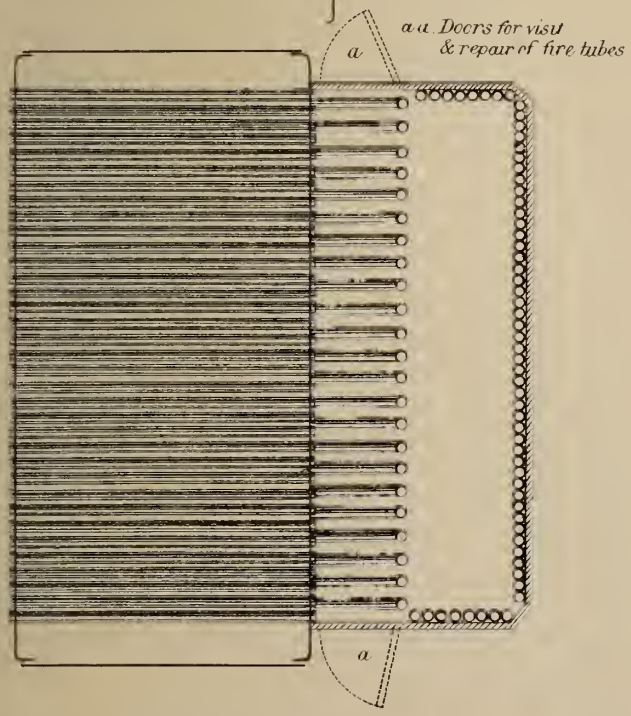
FIG. 1.

DOUBLE ENDED

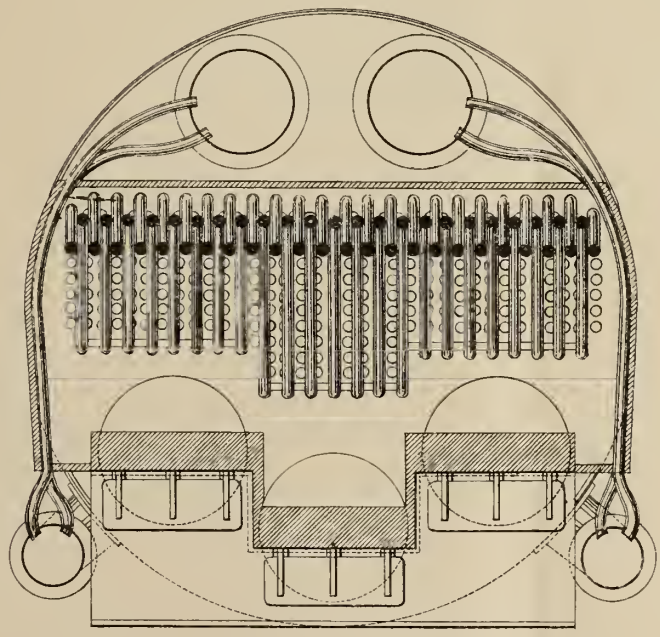


LONGITUDINAL VERTICAL SECTION.

FIG. 2.



HORIZONTAL SECTION.



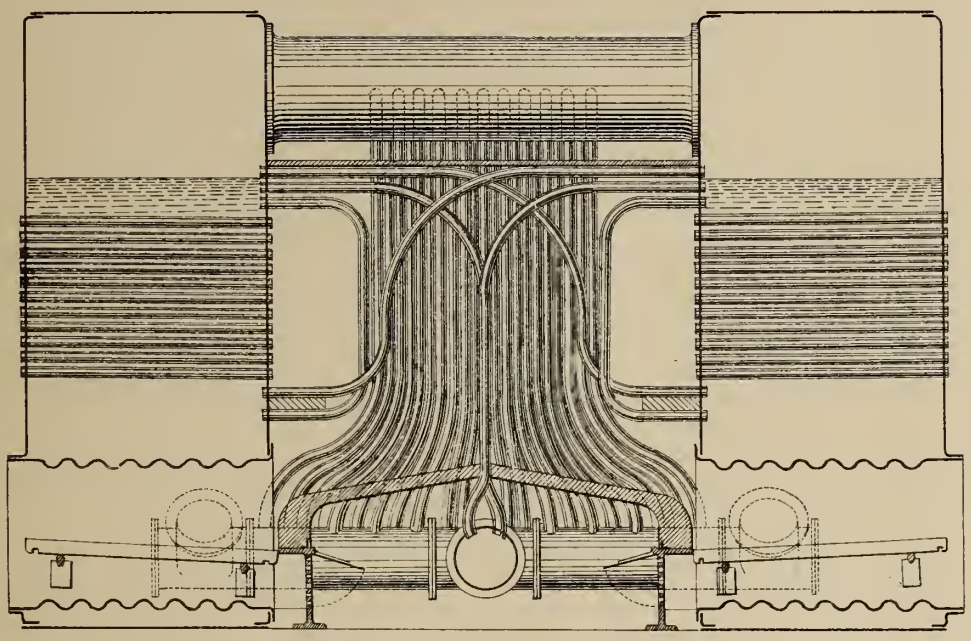
TRANSVERSE VERTICAL SECTION.

To Illustrate Colonel N. Soliani's Paper on compound Marine Boilers.

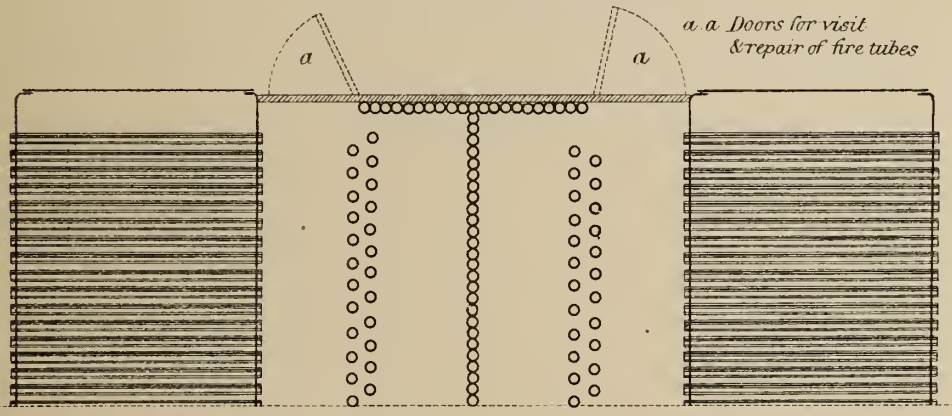
COMPOUND MARINE CYLINDRICAL BOILER

WITH COMBUSTION CHAMBER BUILT UP WITH WATER TUBES.

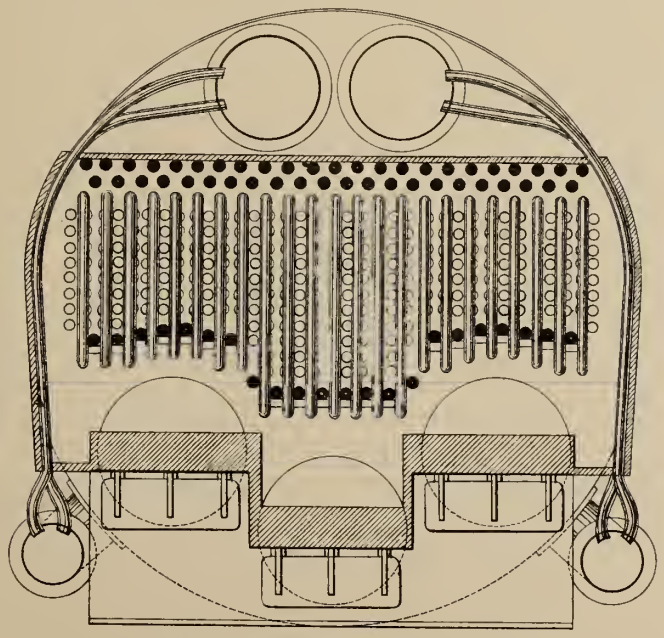
DOUBLE ENDED



LONGITUDINAL VERTICAL SECTION



HORIZONTAL SECTION



TRANSVERSE VERTICAL SECTION

FIG. 3.

To Illustrate Mr. J. Watt's Paper on Water-Tube Boilers.

Fig. 1.

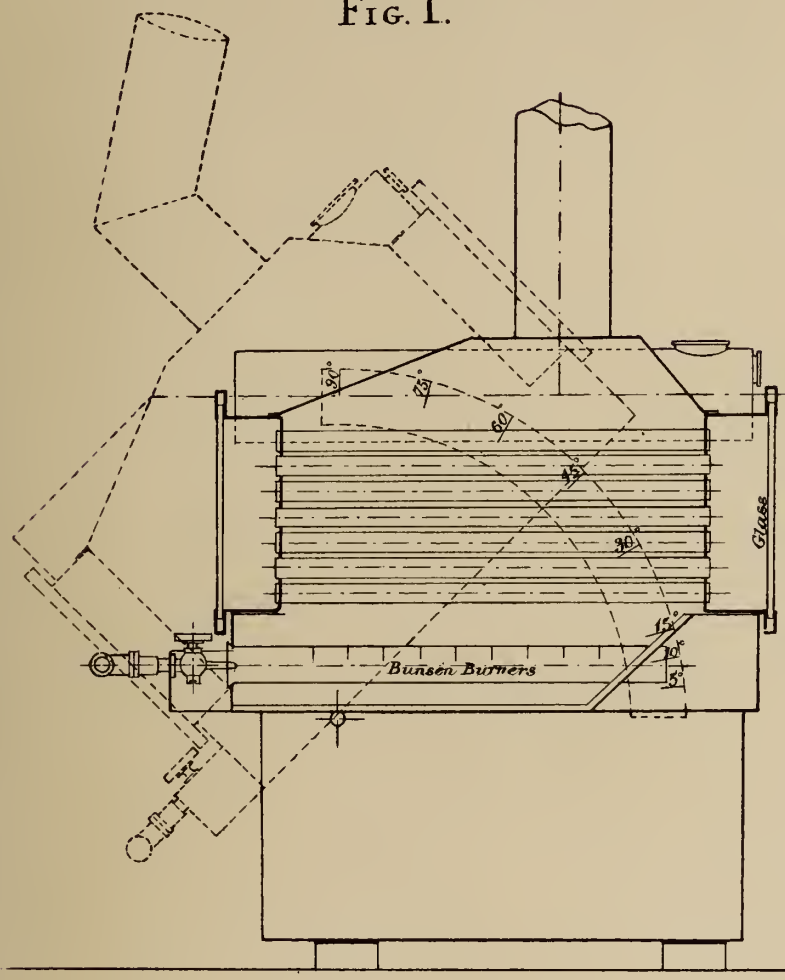


Fig. 2.

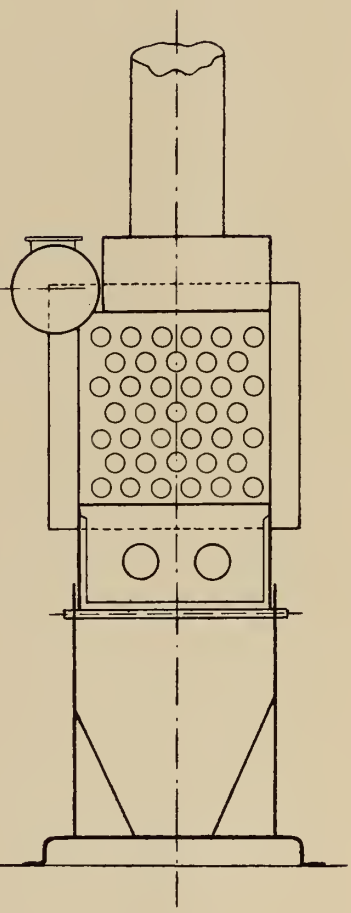


Fig. 2A.

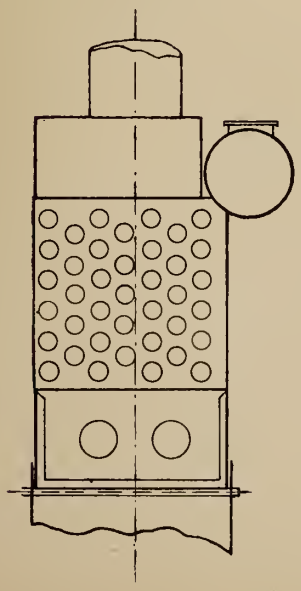
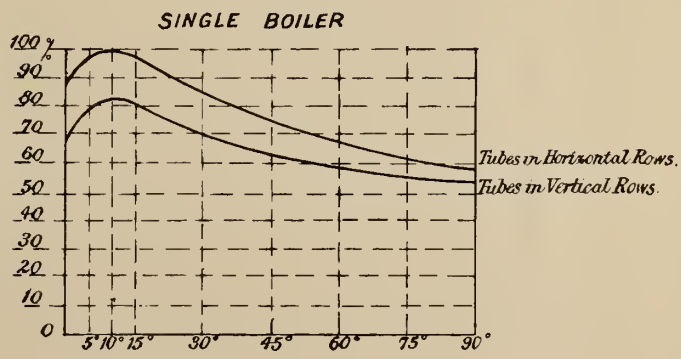


Fig. 3.



To Illustrate Mr. J. Watt's Paper on Water-Tube Boilers.

Fig. 4.

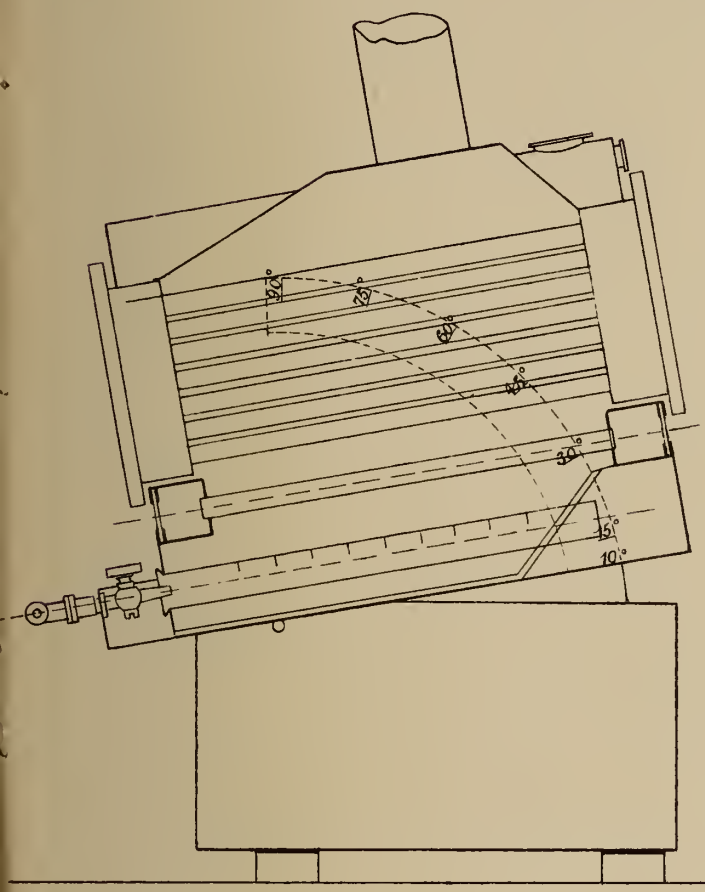


Fig. 6.

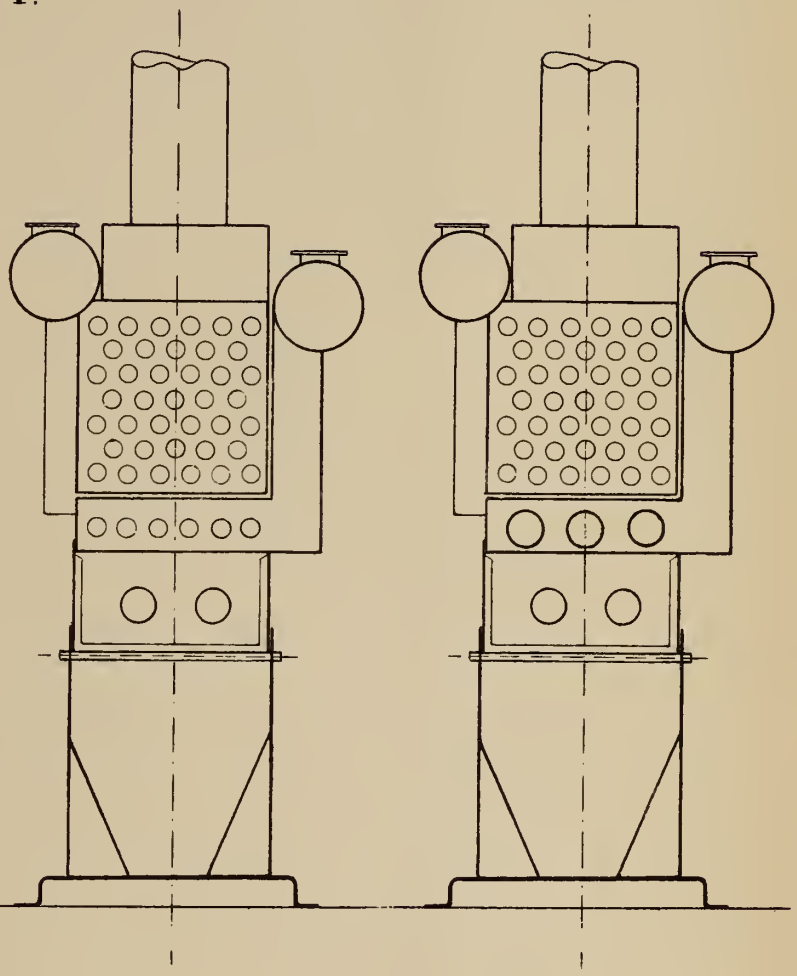


Fig. 5.

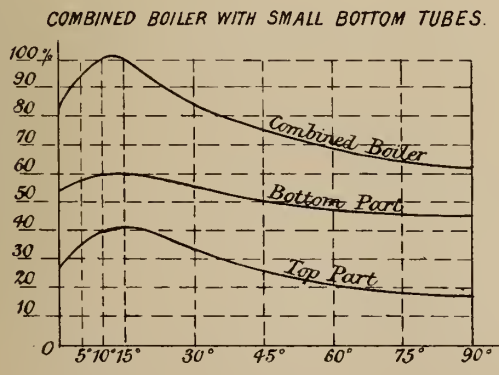
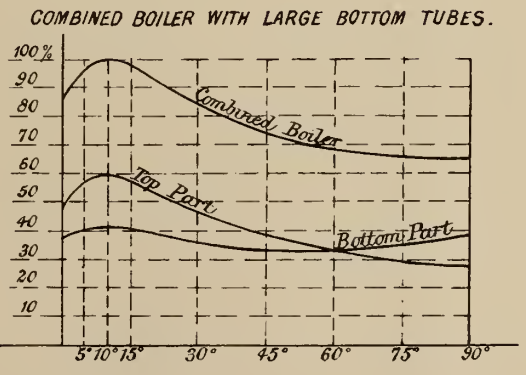


Fig. 7.



To Illustrate Professor W. H. Watkinson's Paper on Circulation in Water-Tube Boilers.

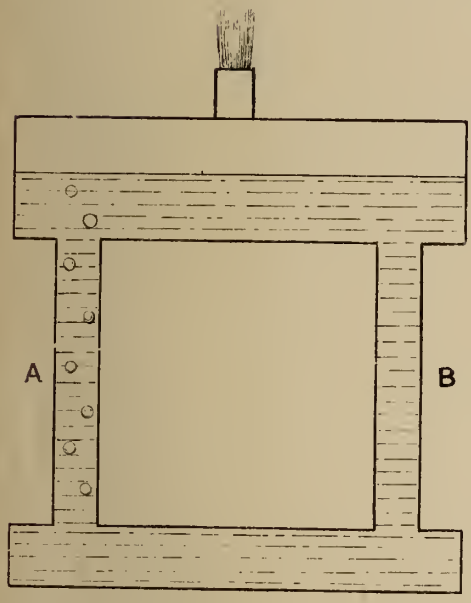


Fig. 1.

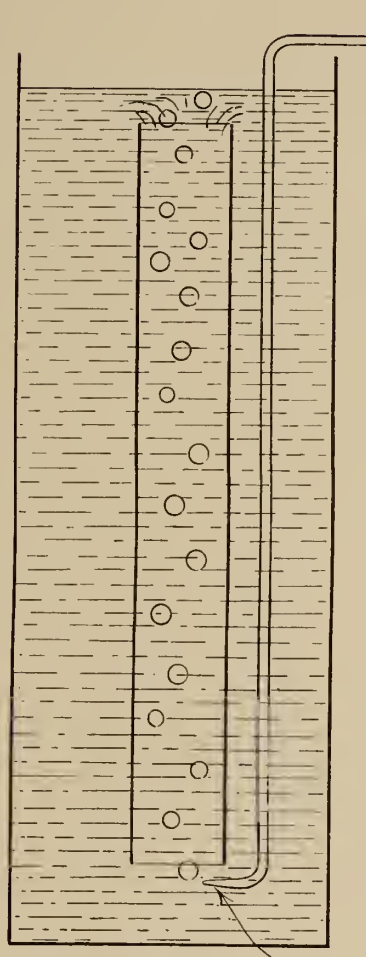


Fig. 2.

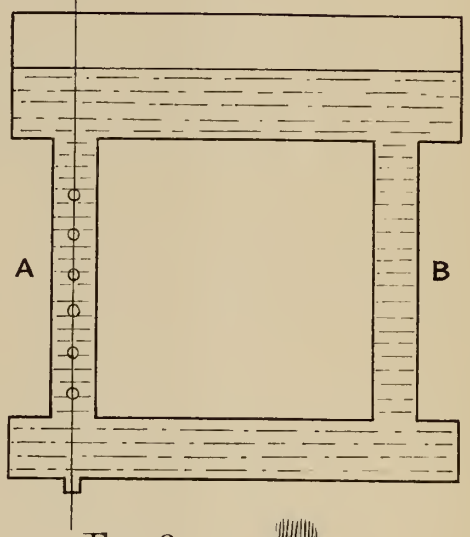


Fig. 3.

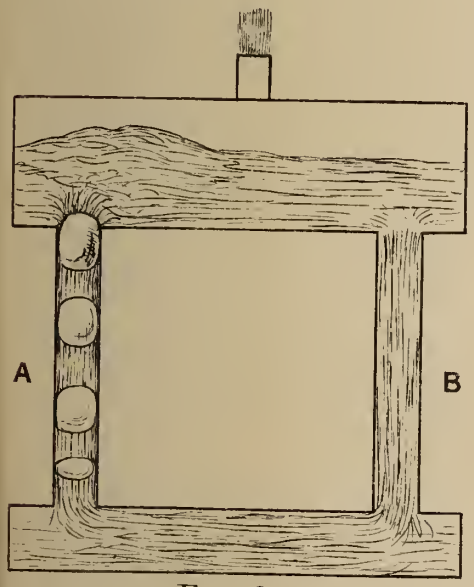


Fig. 4.

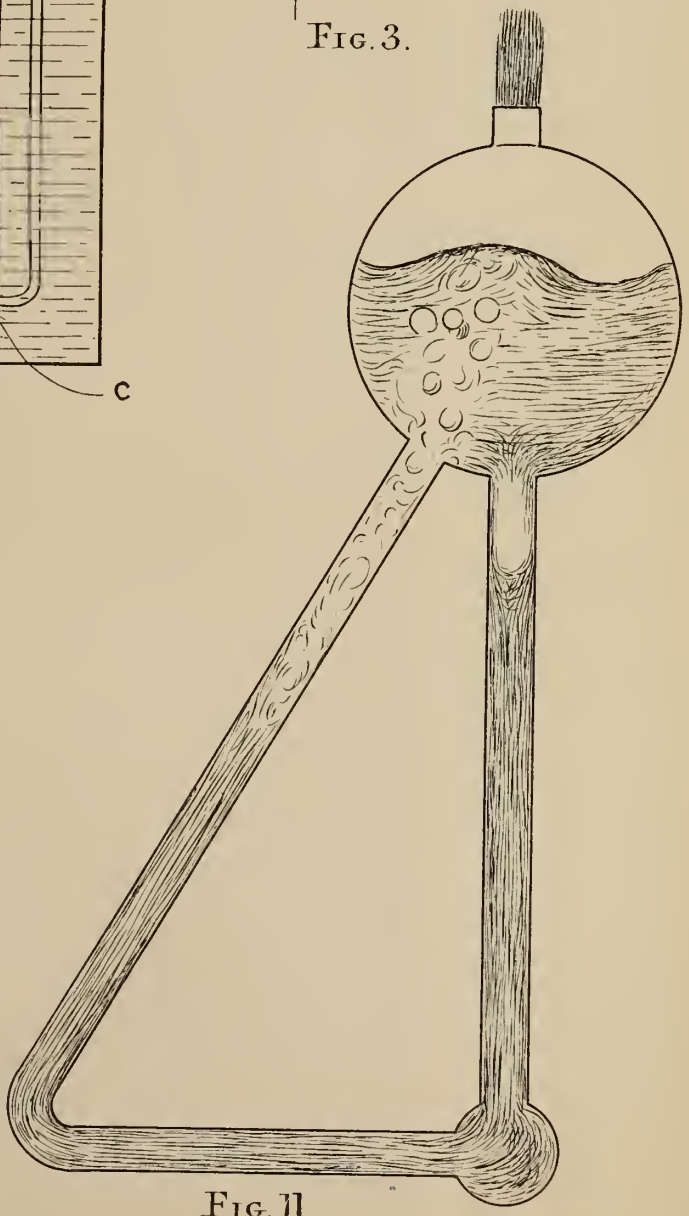


Fig. 11.

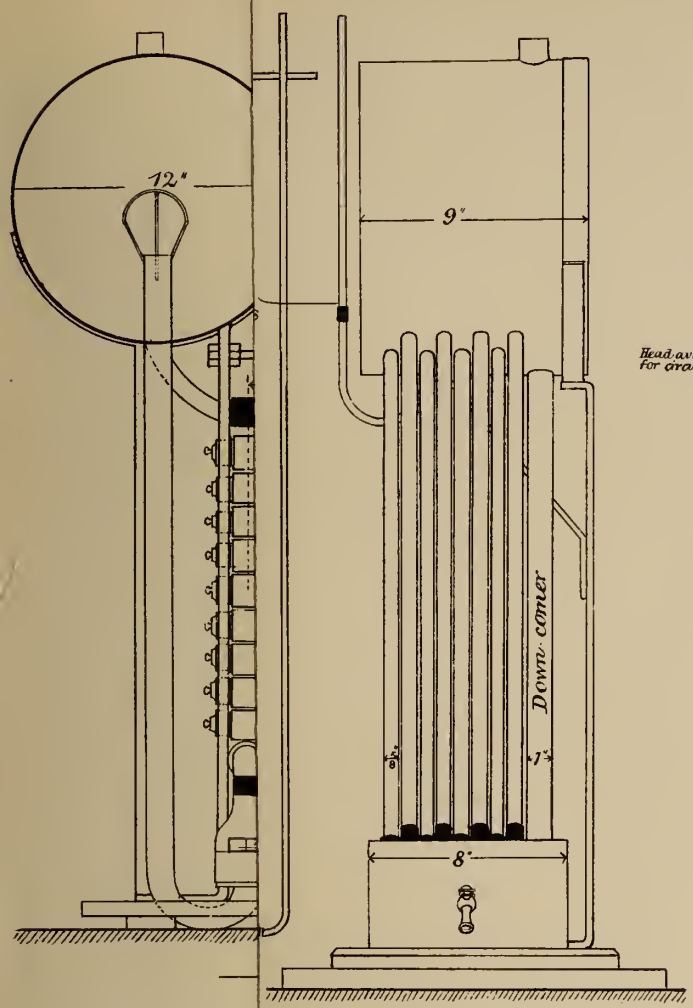
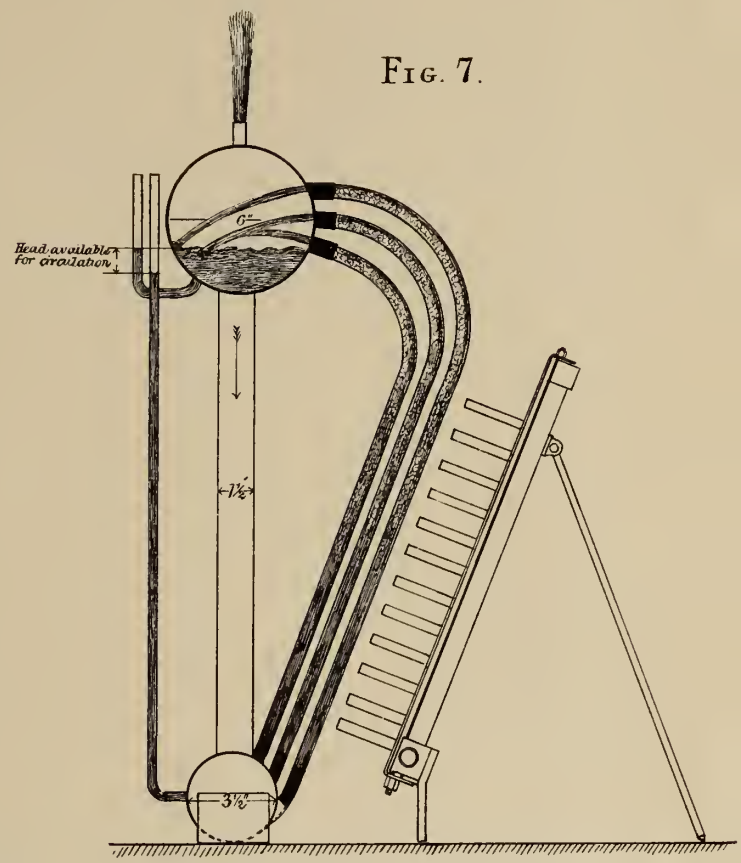
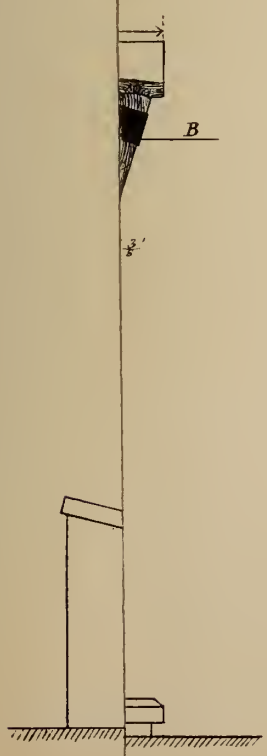


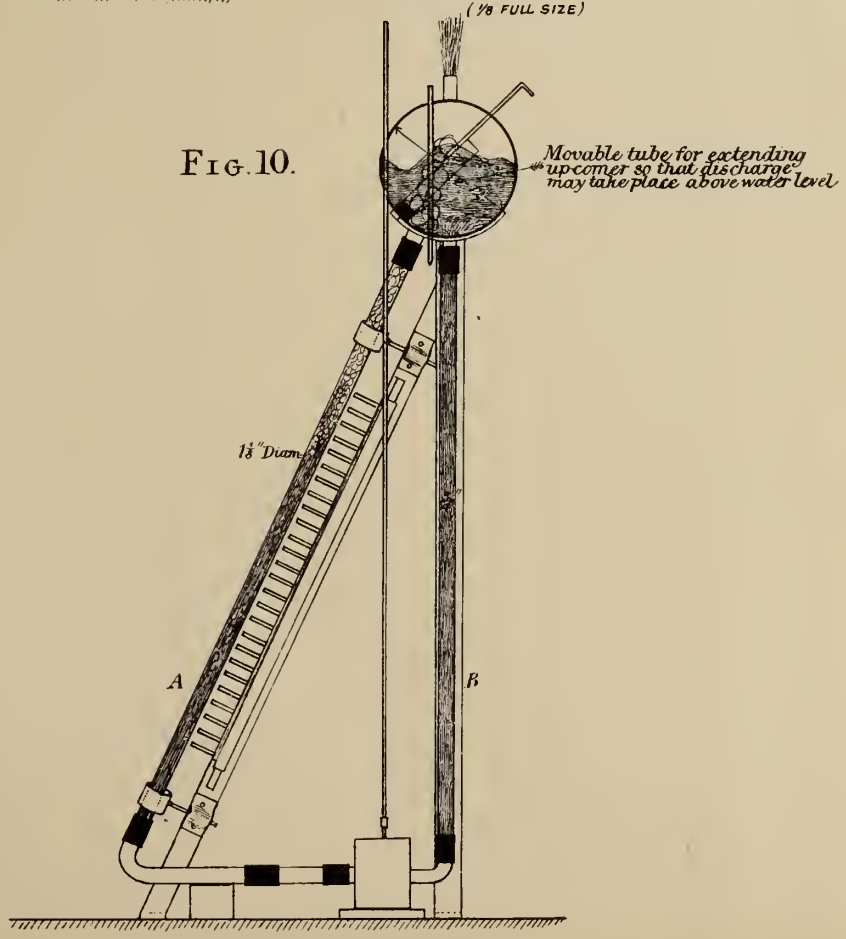
Fig. 7.



MODEL OF THORNEYCROFT BOILER.
(⅛ FULL SIZE)

Fig. 10.





EXPERIMENTAL BOILER.
(1½ FULL SIZE)

To Illustrate Professor W. H. Watkinson's Paper on Circulation in Water-Tube Boilers.

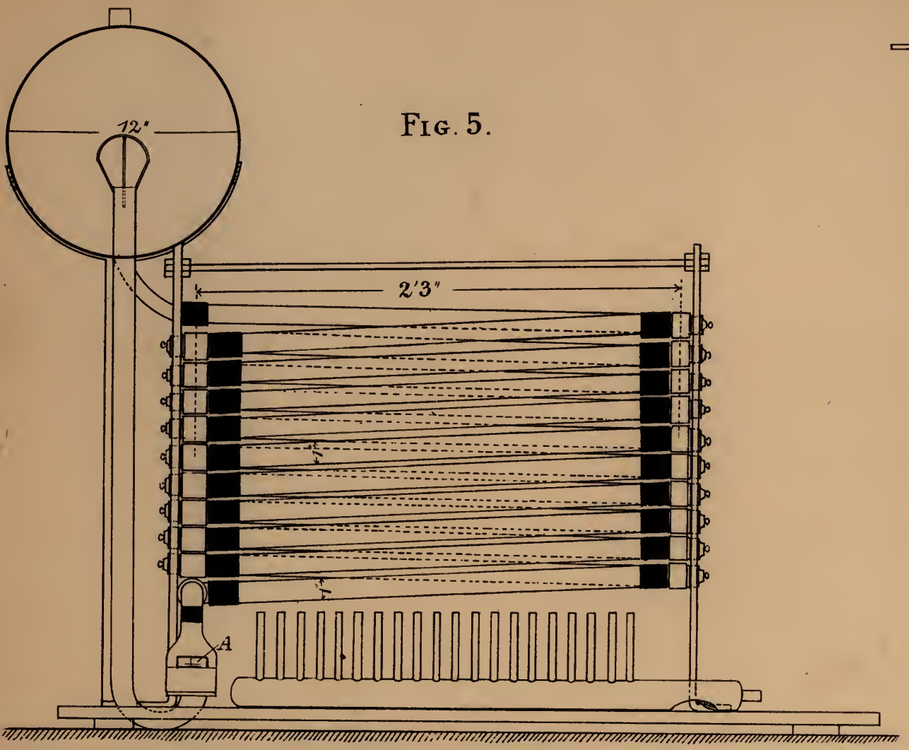


FIG. 5.

MODEL OF BELLEVILLE BOILER.
(1/8 FULL SIZE)

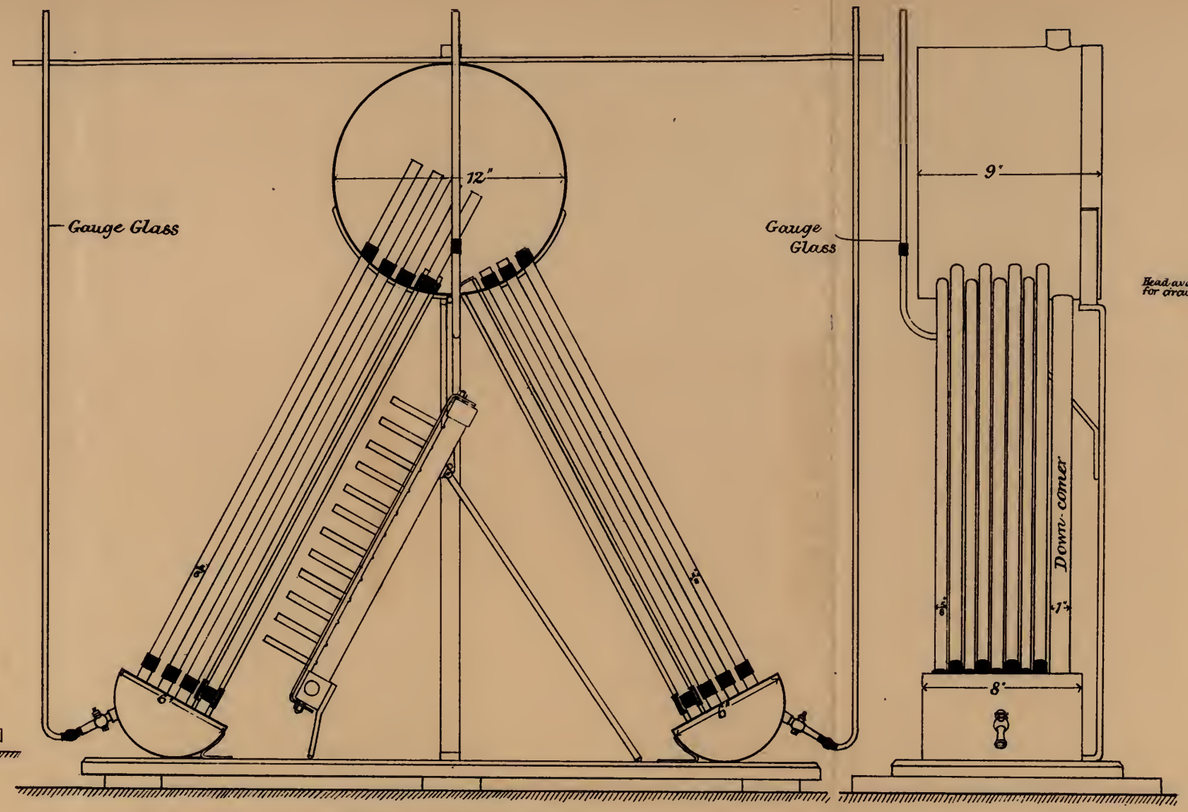


FIG. 6. MODEL OF YARROW BOILER.
(1/8 FULL SIZE)

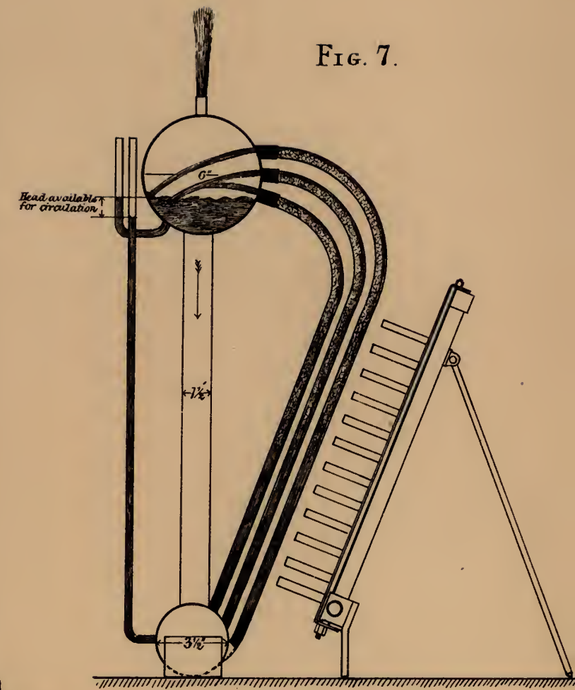


FIG. 7.

MODEL OF THORNEYCROFT BOILER.
(1/8 FULL SIZE)

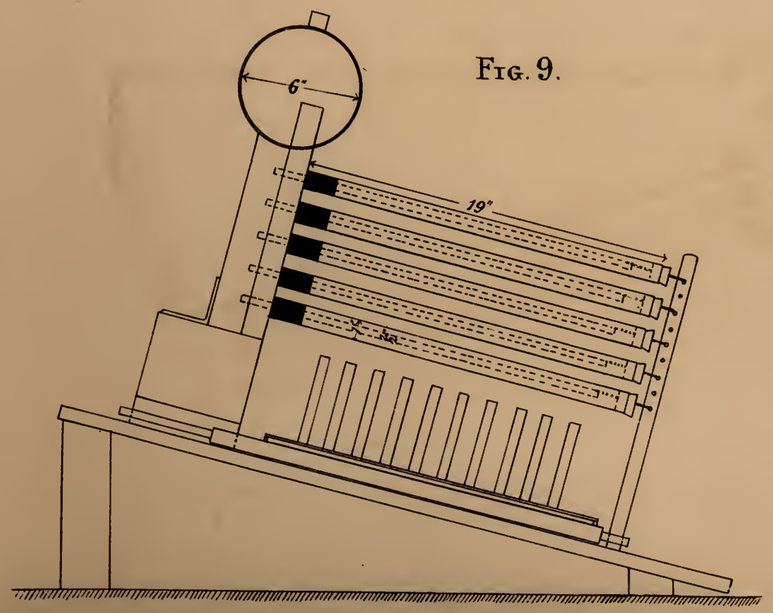


FIG. 9.

MODEL OF NICLAUSSE BOILER.
(1/8 FULL SIZE)

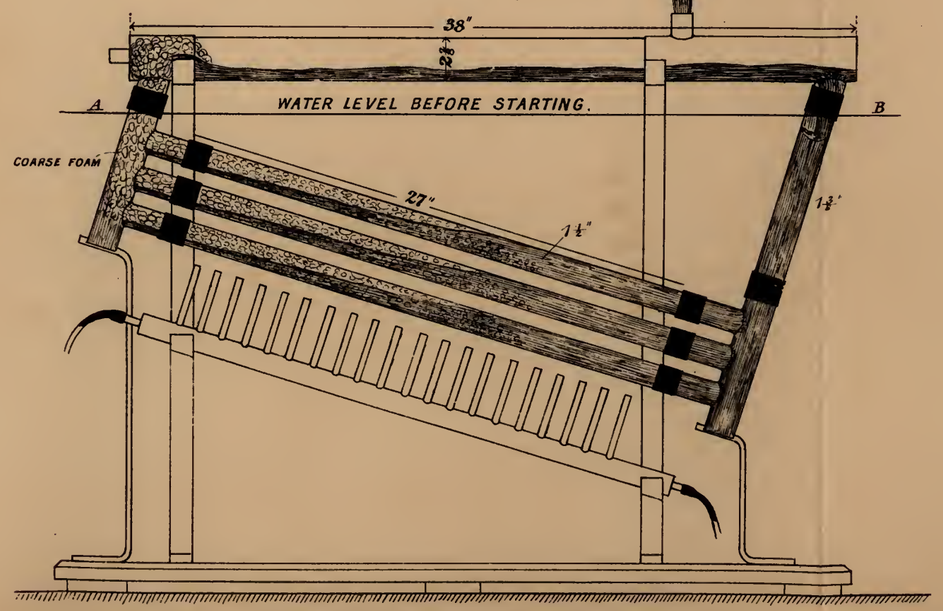


FIG. 8.

MODEL OF BABCOCK AND WILLCOX BOILER.
(1/8 FULL SIZE)

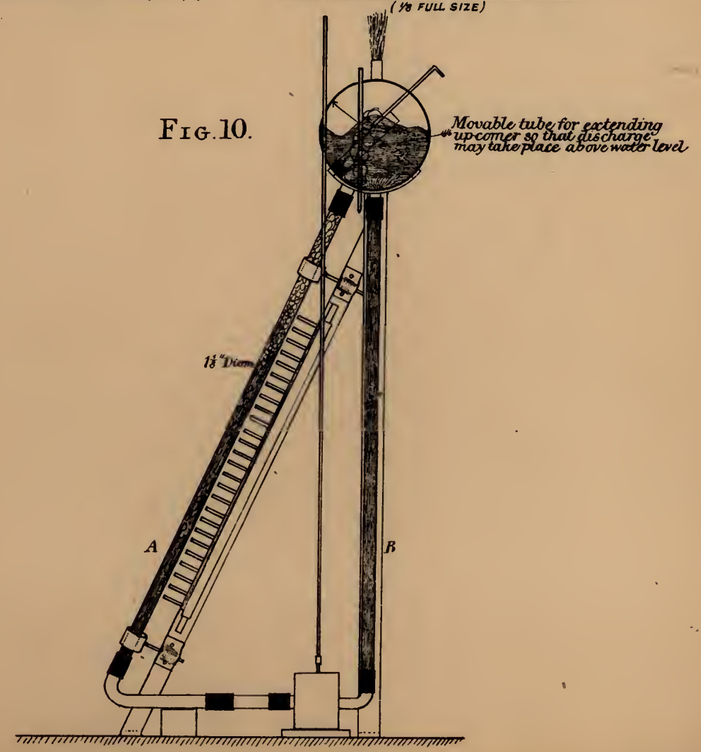


FIG. 10.

EXPERIMENTAL BOILER.

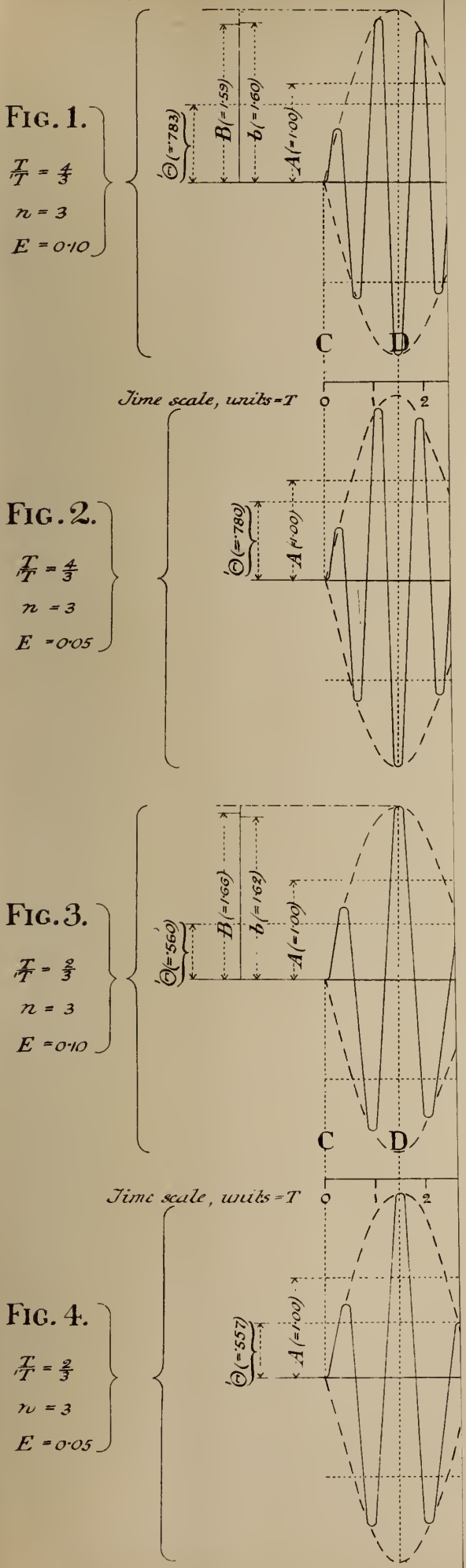


Fig. 1.
T/T' = 4/3
n = 3
E = 0·10
Θ (=·783)
B (=1·59)
b (=1·60)
A (=1·00)
C
D
Time scale, units = T
0
1
2
Fig. 2.
T/T' = 4/3
n = 3
E = 0·05
Θ (=·780)
A (=1·00)
Fig. 3.
T/T' = 2/3
n = 3
E = 0·10
Θ (=·560)
B (=1·66)
b (=1·62)
A (=1·00)
C
D
Time scale, units = T
0
1
2
Fig. 4.
T/T' = 2/3
n = 3
E = 0·05
Θ (=·557)
A (=1·00)

To Illustrate Mr. R. E. Froude's Paper on The non-uniform Rolling of Ships.

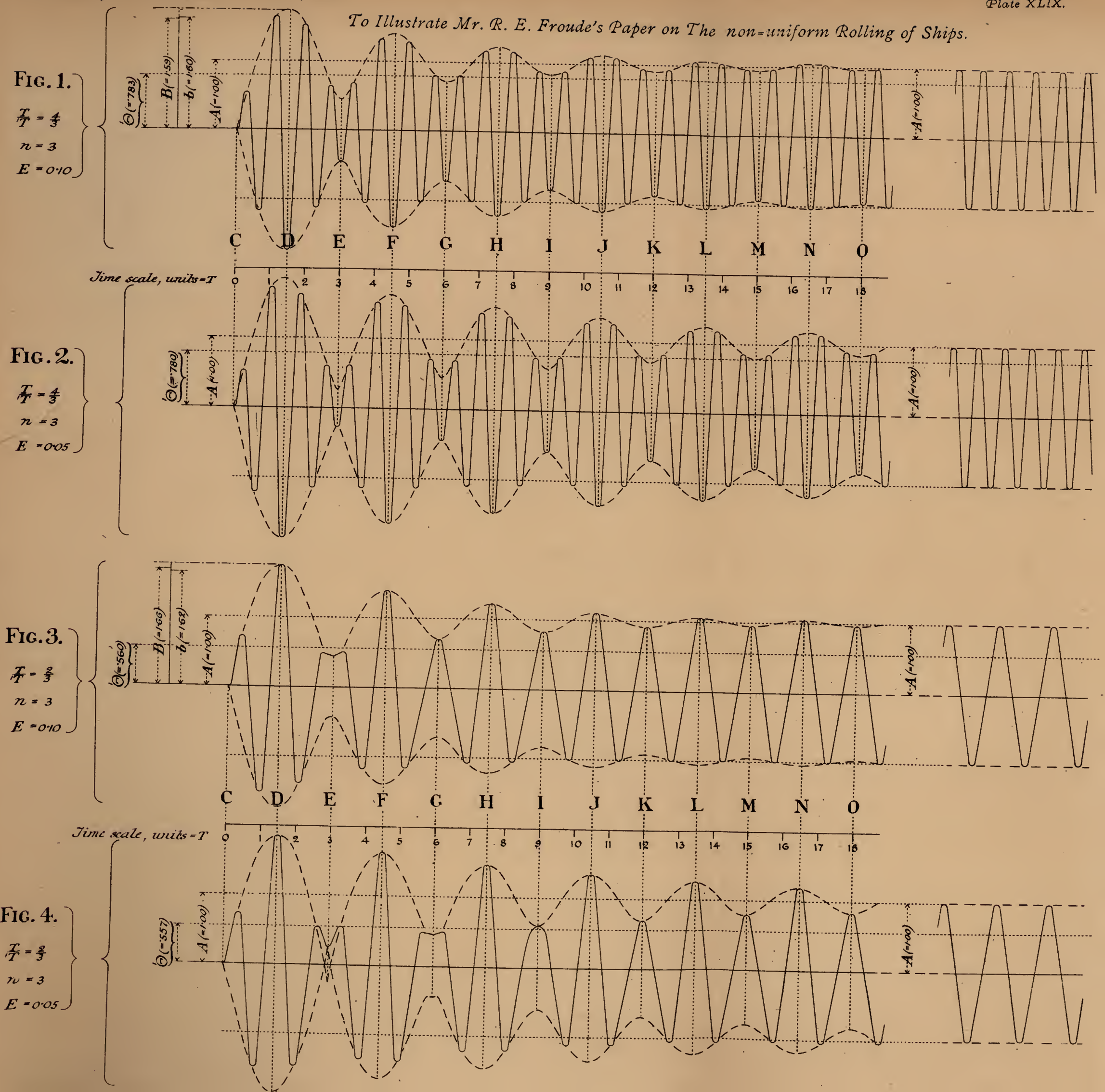
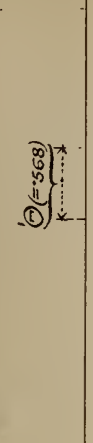


FIG. 5.

$\frac{T}{T'} = \frac{5}{4}$

$n = 4$

$E = 0{\cdot}10$



Time scale, i

FIG. 6.

$\frac{T}{T'} = \frac{5}{4}$

$n = 4$

$E = 0{\cdot}05$

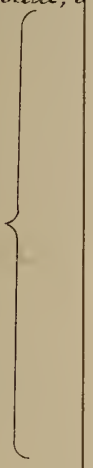
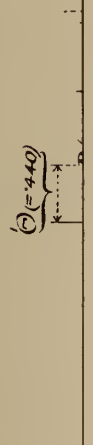


FIG. 7.

$\frac{T}{T'} = \frac{3}{4}$

$n = 4$

$E = 0{\cdot}10$



Time scale,

FIG. 8.

$\frac{T}{T'} = \frac{3}{4}$

$n = 4$

$E = 0{\cdot}05$

To Illustrate Mr. R. E. Froude's Paper on The non-uniform Rolling of Ships.

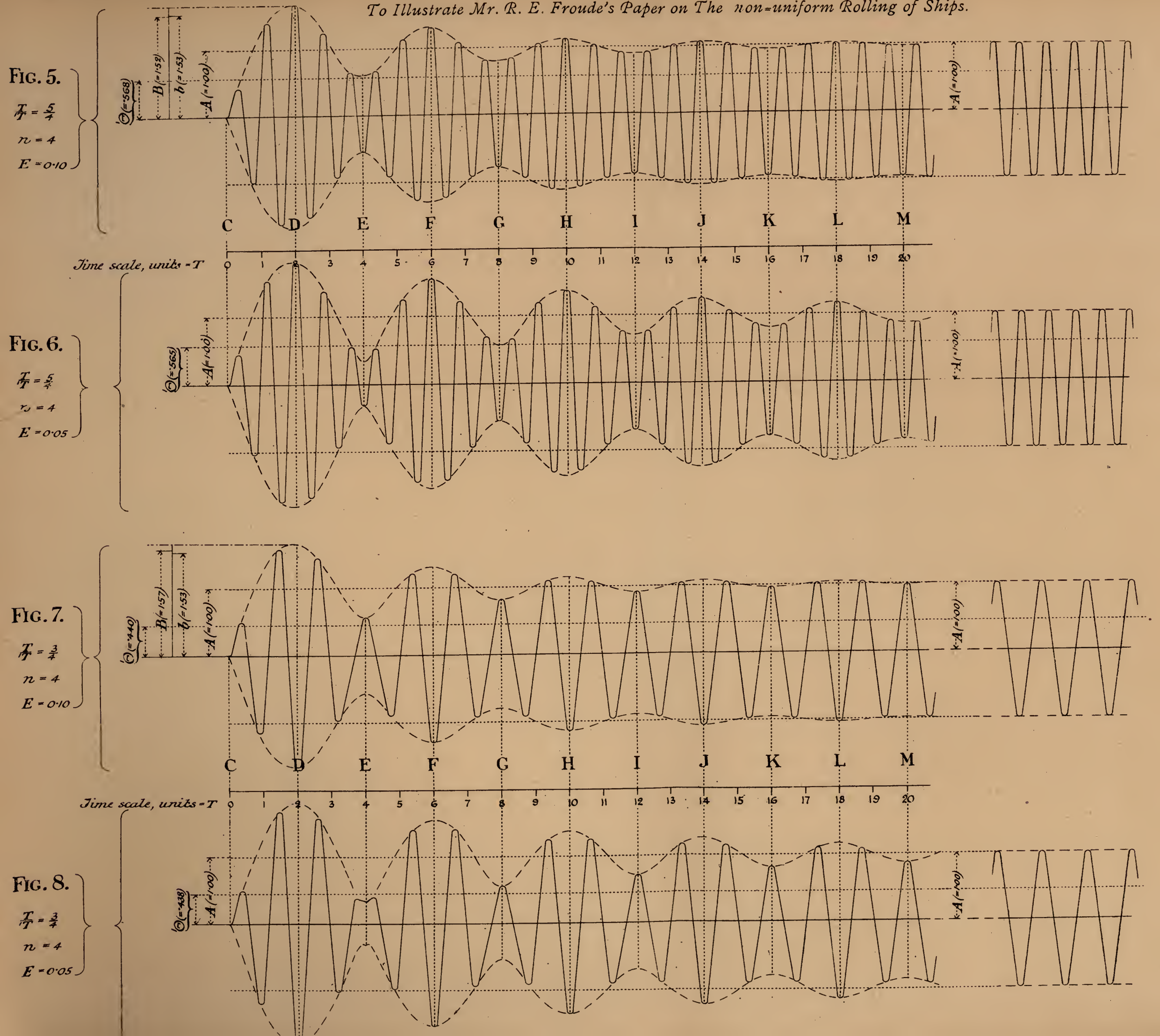


Fig. 9.

$\frac{T}{T} = \frac{7}{6}$

$n = 6$

$E = 0{\cdot}10$

Time sca

Fig. 10.

$\frac{T}{T} = \frac{7}{6}$

$n = 6$

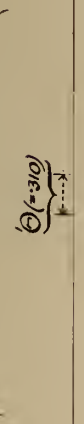
$E = 0{\cdot}05$

Fig. 11.

$\frac{T}{T} = \frac{5}{6}$

$n = 6$

$E = 0{\cdot}10$



Time scal

Fig. 12.

$\frac{T}{T} = \frac{5}{6}$

$n = 6$

$E = 0{\cdot}05$

To Illustrate Mr. R. E. Froude's Paper on The non-uniform Rolling of Ships.

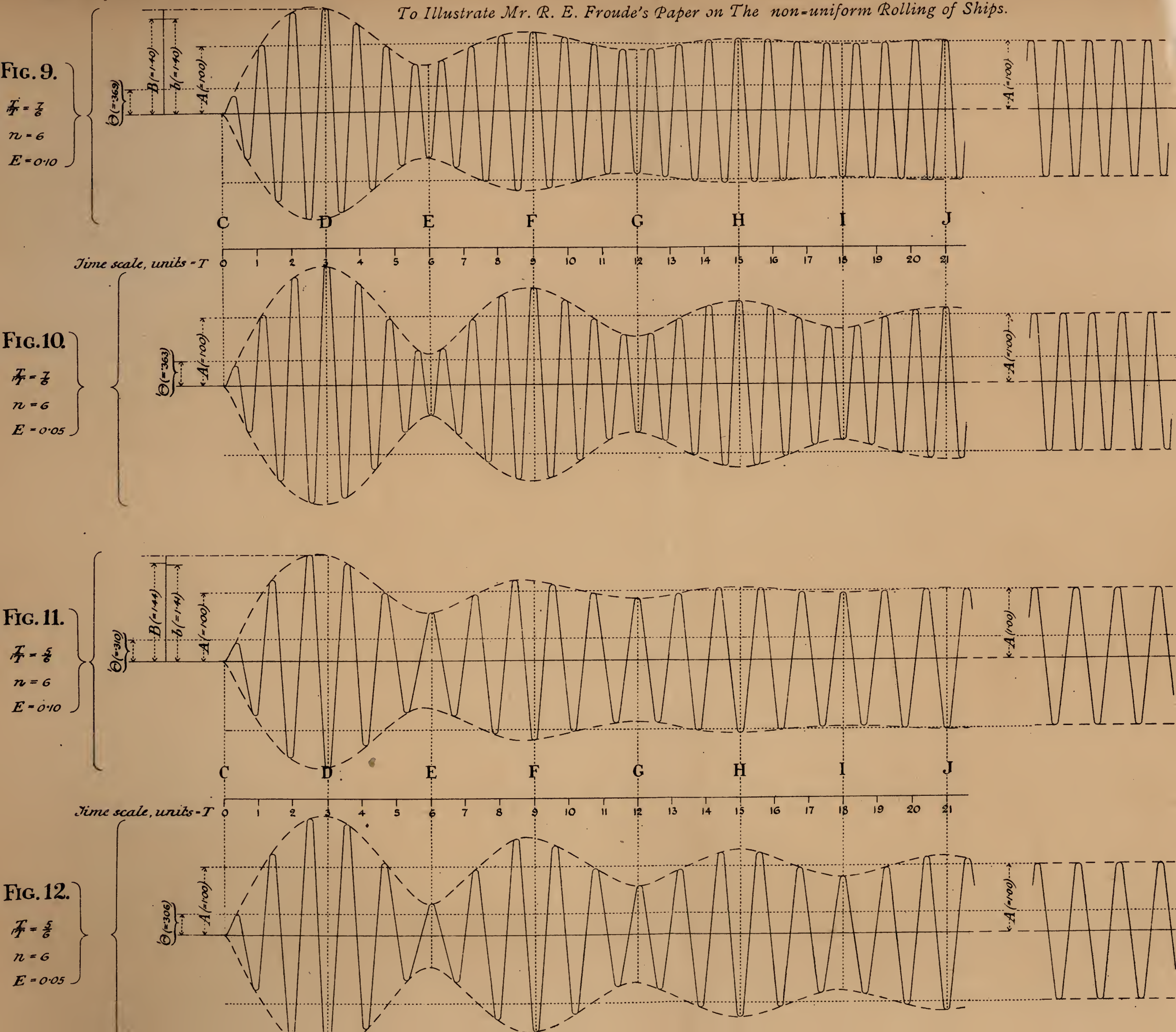


Fig. 13.

$\frac{T}{T'} = \frac{11}{10}$

$n = 10$

$E = 0{\cdot}10$

Fig. 14.

$\frac{T}{T'} = \frac{11}{10}$

$n = 10$

$E = 0{\cdot}05$

Fig. 15.

$\frac{T}{T'} = \frac{9}{10}$

$n = 10$

$E = 0{\cdot}10$

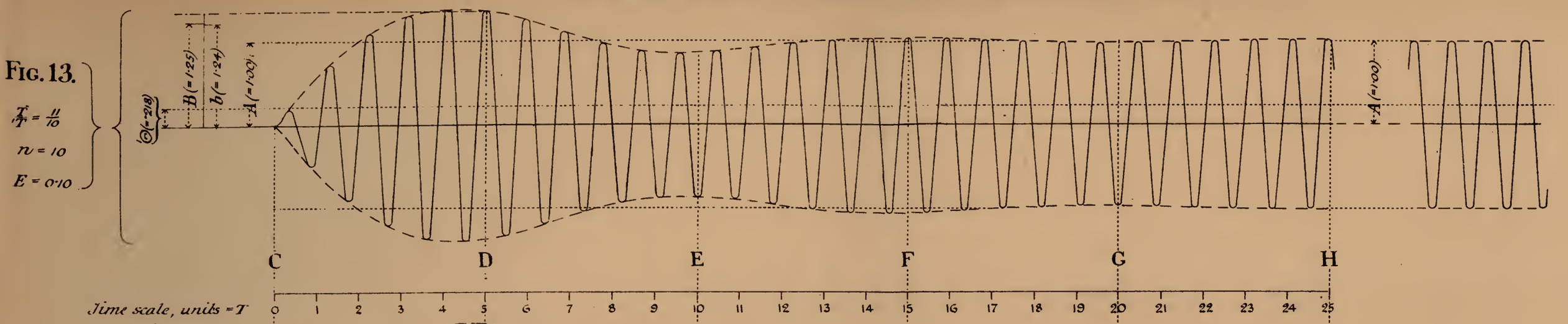
Fig. 16.

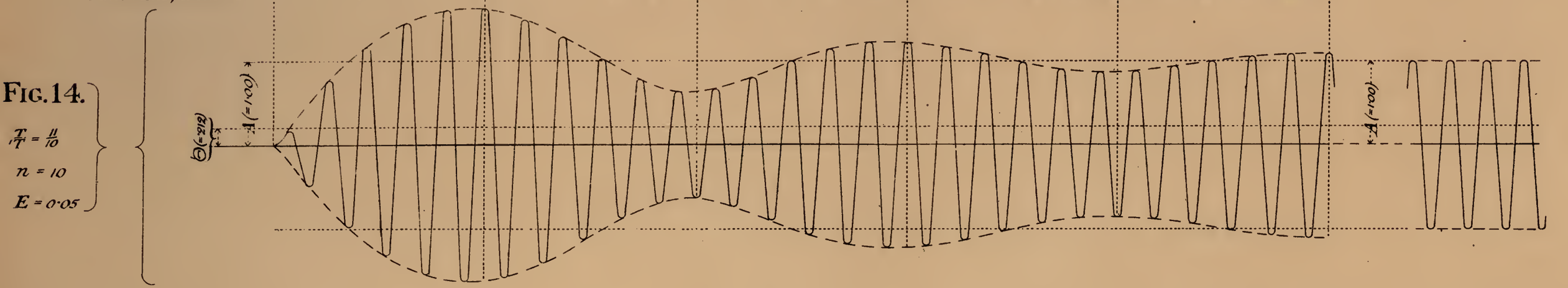
$\frac{T}{T'} = \frac{9}{10}$

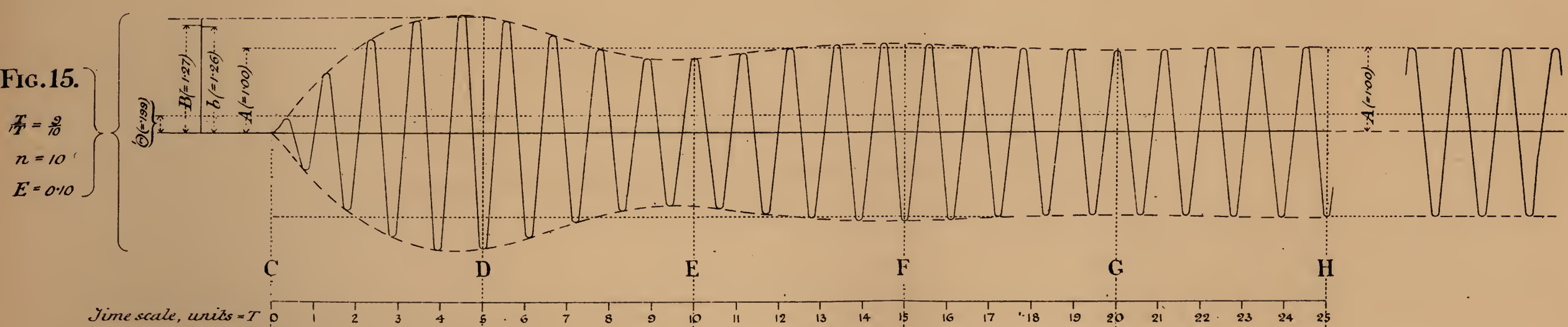
$n = 10$

$E = 0{\cdot}05$

To Illustrate Mr. R. E. Froude's Paper on The non-uniform Rolling of Ships.







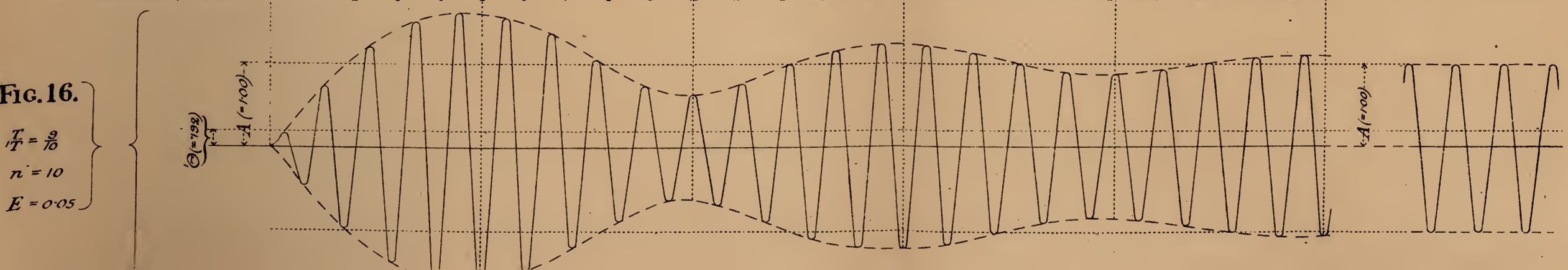


Fig. 17.

$\frac{T}{T'} = 1$

$n = \infty$

$E = 0{\cdot}10$

$\theta' (= 0{\cdot}64)$

Time scale, units

Fig. 18.

$\frac{T}{T'} = 1$

$n = \infty$

$E = 0{\cdot}05$

$\theta' (= 0{\cdot}32)$

To Illustrate Mr. R. E. Froude's Paper on The non-uniform Rolling of Ships.

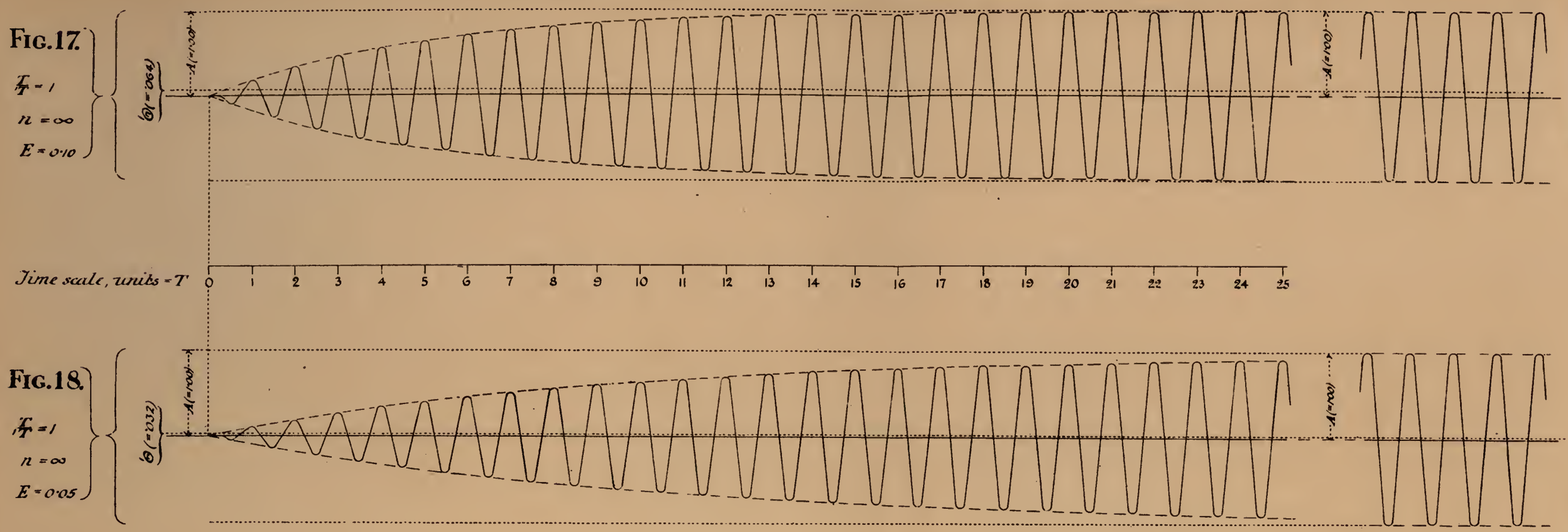
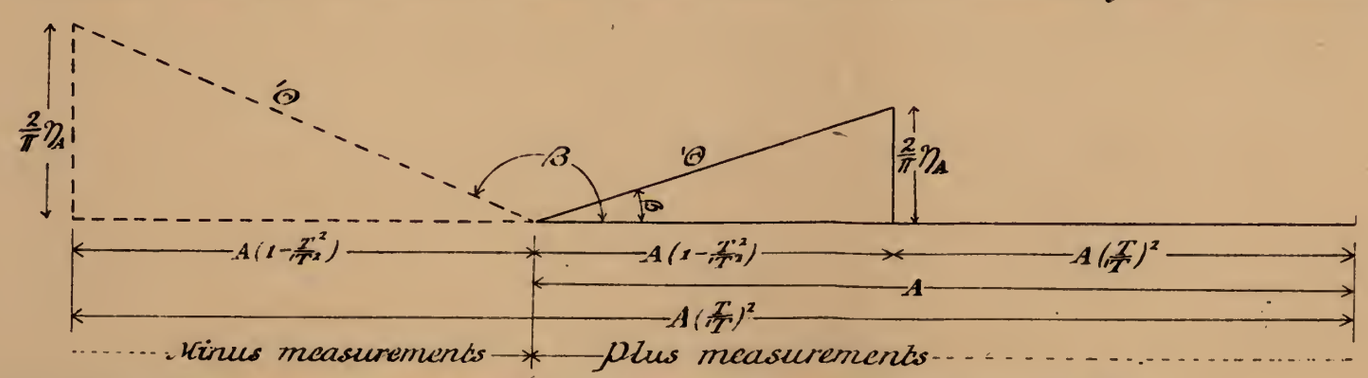


FIG. 19. *Shewing relation of A to Θ, and "phase angle" β., for resisted (forced) oscillation.*



NB:- The dotted portion of the figure (as follows from the signs) is for $\frac{T}{T} > 1$.

The "phase angle" β, divided by 2π, expresses the fraction of T by which the extreme wave slope precedes the extreme angle of ship in the same direction.

η_A is the extinction (or $\frac{d\theta}{dn}$) proper to the amplitude A when the oscillation takes place in period = T; and = $EA\frac{T}{T}$, for the conventional assumption as to resistance.

[The above figure is drawn correctly for the following values; $\frac{T}{T} = \frac{3}{4}$ and $\frac{5}{4}$; $E = 0{\cdot}3$]

To Illustrate Captain A. Kriloff's Paper on a new Theory of the pitching Motion of Ships on Waves and of the Stresses produced by this Motion.

Scale $\frac{1}{800}$

DIMENSIONS OF THE SHIP

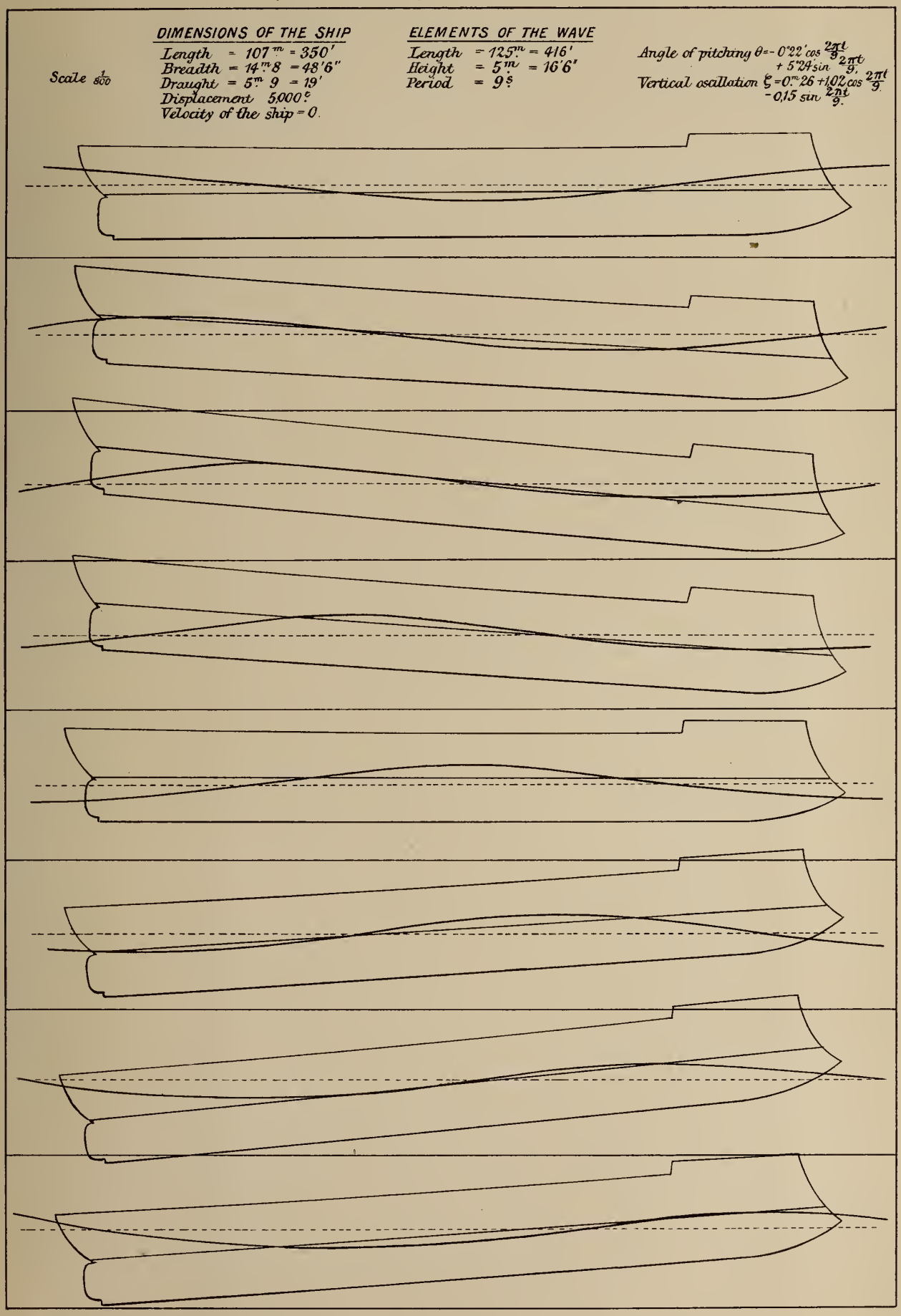
Length = 107.m = 350'
Breadth = 14.m 8 = 48'6"
Draught = 5.m 9 = 19'
Displacement 5,000.t
Velocity of the ship = 0.

ELEMENTS OF THE WAVE

Length = 125.m = 416'
Height = 5.m = 16'6'
Period = 9.s

Angle of pitching $\theta = -0°22' \cos \frac{2\pi t}{9} + 5°24' \sin \frac{2\pi t}{9}$

Vertical oscillation $\xi = 0.m26 + 1,02 \cos \frac{2\pi t}{9} - 0,15 \sin \frac{2\pi t}{9}$



To Illustrate Captain A Kriloff's Paper on a new Theory of the pitching Motion of Ships on Waves and of the Stresses produced by this Motion.

Scale $\frac{1}{800}$

DIMENSIONS OF THE SHIP

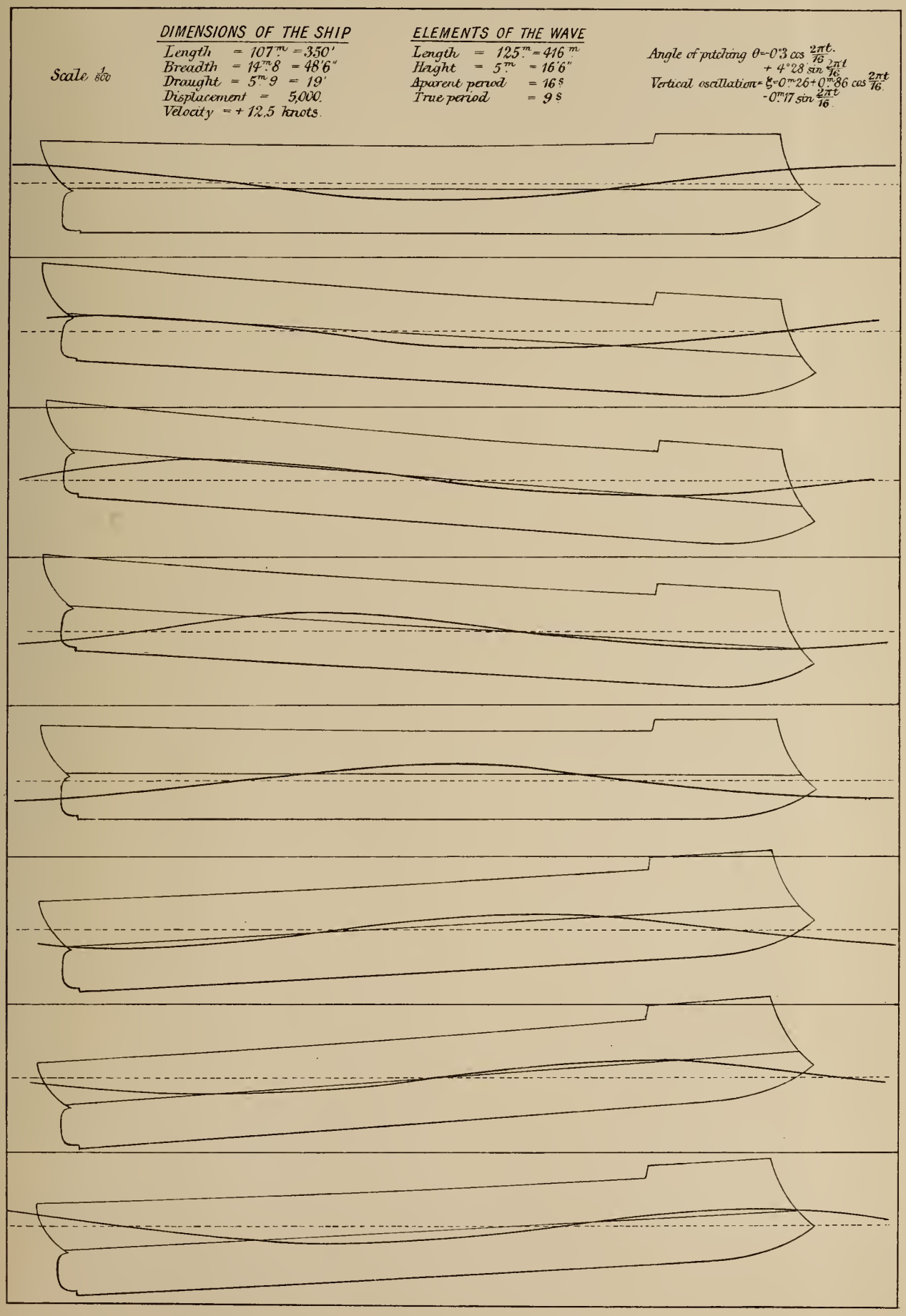
Length = 107.m = 350'
Breadth = 14.m8 = 48'6"
Draught = 5.m9 = 19'
Displacement = 5,000.
Velocity = + 12.5 knots.

ELEMENTS OF THE WAVE

Length = 125.m = 416 m
Height = 5.m = 16'6"
Apparent period = 16 s
True period = 9 s

Angle of pitching $\theta = -0°.3 \cos \frac{2\pi t}{16} + 4°.28 \sin \frac{2\pi t}{16}$

Vertical oscillation $= \xi = 0^m.26 + 0^m.86 \cos \frac{2\pi t}{16} - 0^m.17 \sin \frac{2\pi t}{16}$



To Illustrate Captain A. Kriloff's Paper on a new Theory of the pitching Motion of Ships on Waves and of the Stresses produced by this Motion.

Scale $\frac{1}{800}$

DIMENSIONS OF THE SHIP.

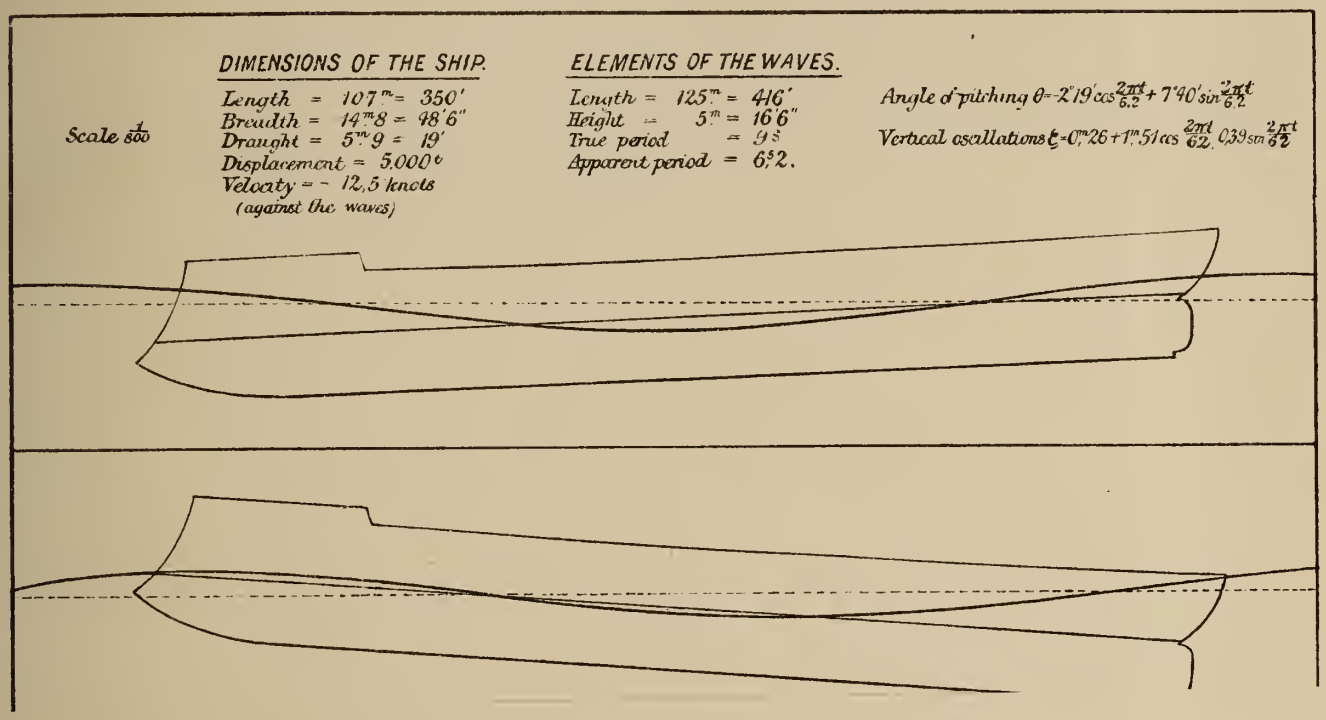
Length = 107^m = 350′
Breadth = 14^{m}8 = 48′6″
Draught = 5^{m}9 = 19′
Displacement = 5,000 t
Velocity = 12,5 knots
(against the waves)

ELEMENTS OF THE WAVES.

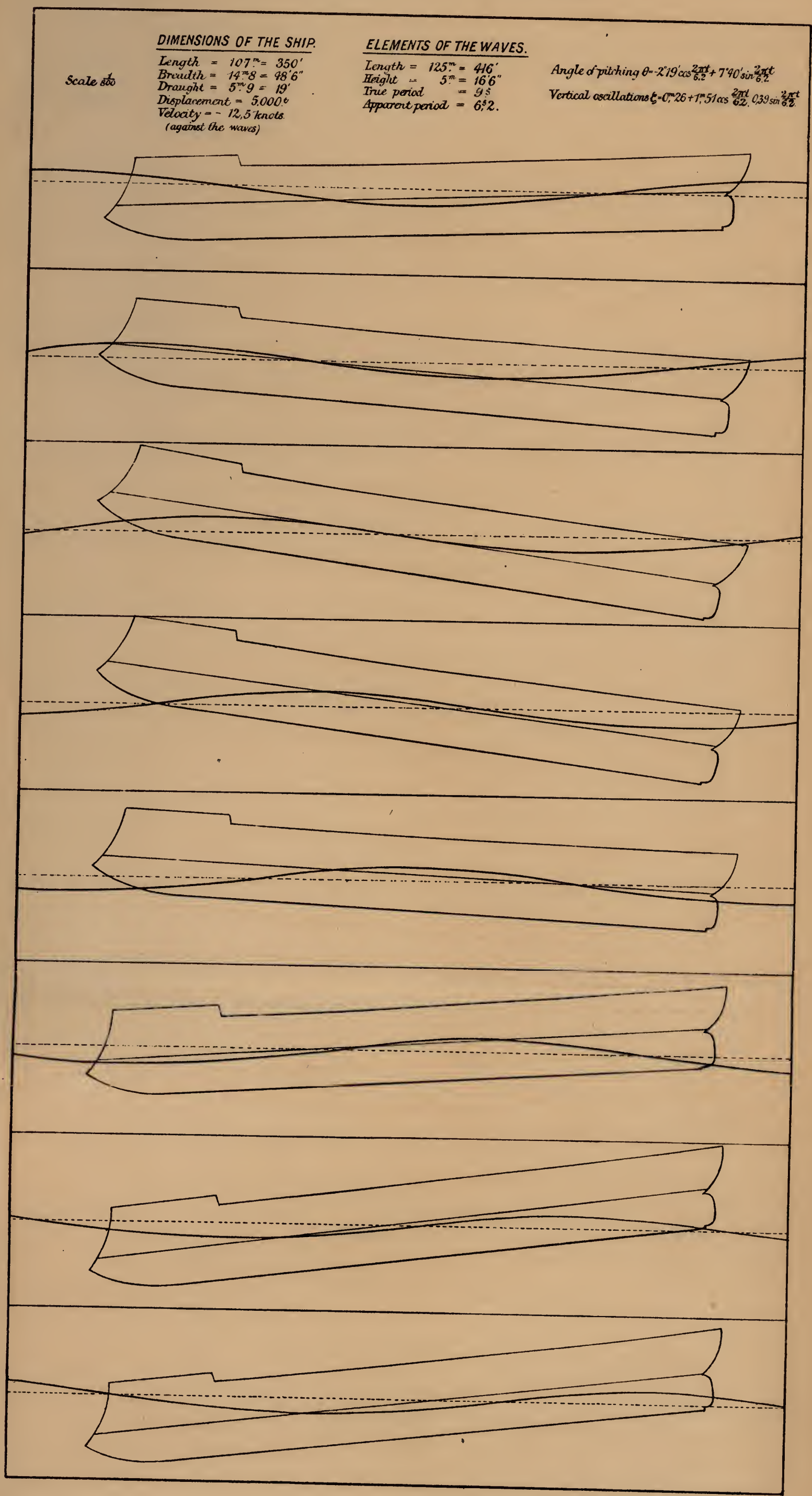
Length = 125^m = 416′
Height = 5^m = 16′6″
True period = 9^s
Apparent period = 6^{s}2.

Angle of pitching $\theta = 2°19' \cos\frac{2\pi t}{6.2} + 7°40' \sin\frac{2\pi t}{6.2}$

Vertical oscillations $\xi = 0^m26 + 1^m51 \cos\frac{2\pi t}{6.2}, 0{,}39 \sin\frac{2\pi t}{6.2}$



To Illustrate Captain A. Kriloff's Paper on a new Theory of the pitching Motion of Ships on Waves and of the Stresses produced by this Motion.



To Illustrate Captain A. Kriloff's Paper on a new Theory of the pitching Motion of Ships on Waves and of the Stresses produced by this Motion.

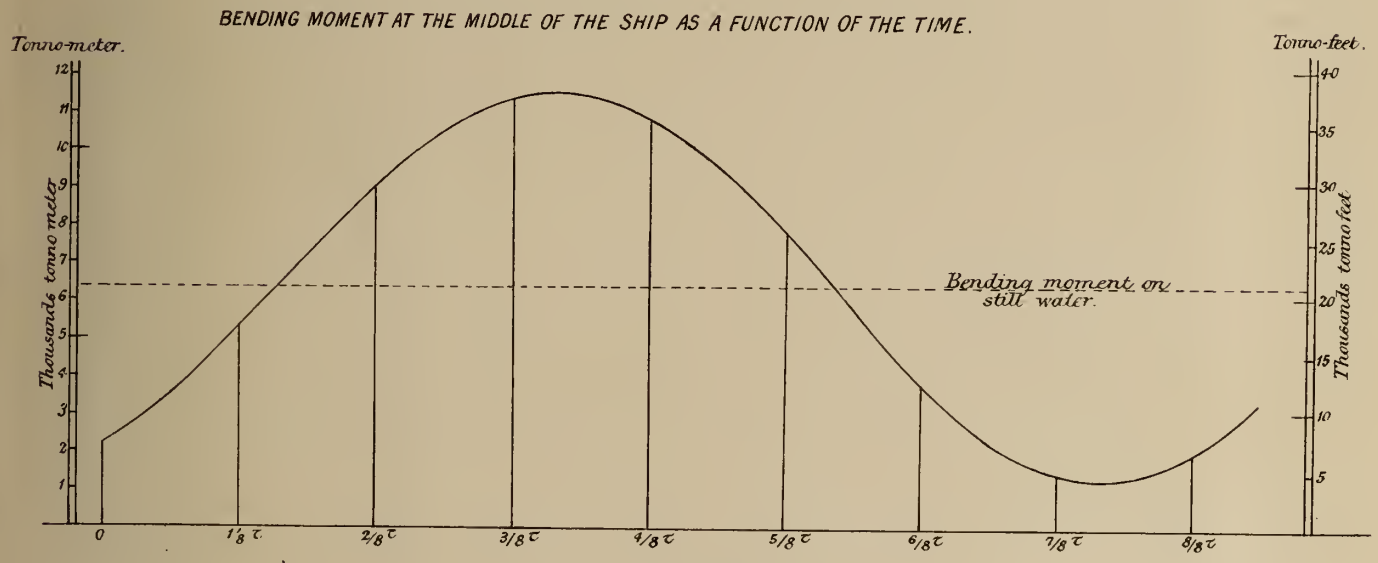


FIG. 1.

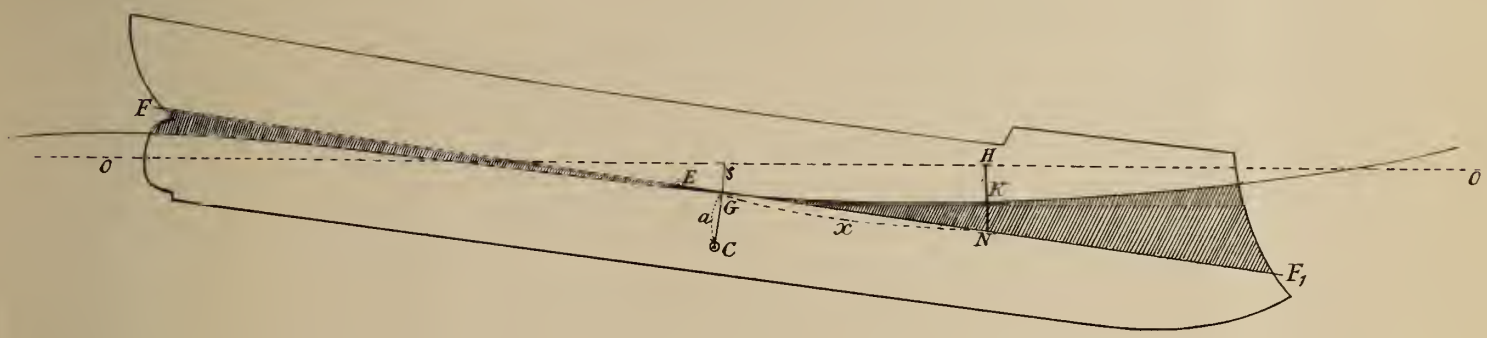


FIG. 2.

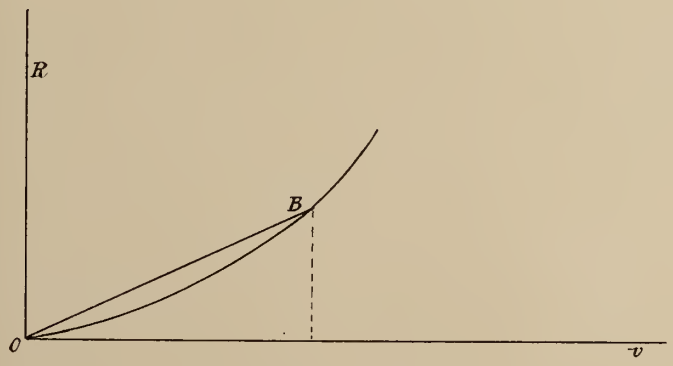


FIG. 3.

FIG. 2. S.S.A. G.M=·67

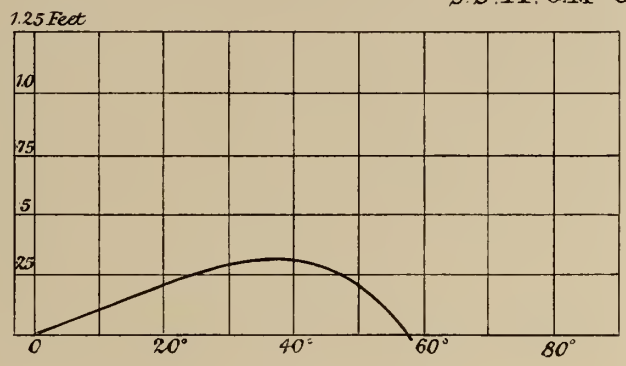
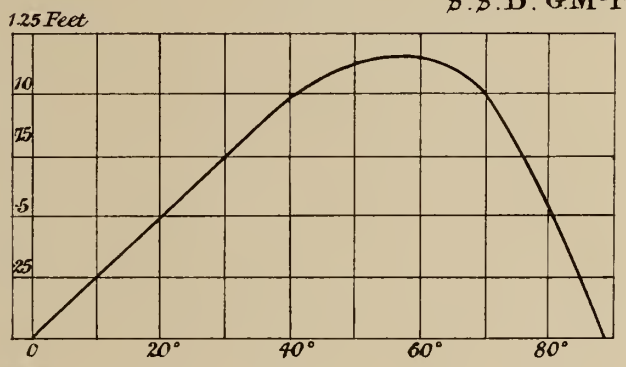
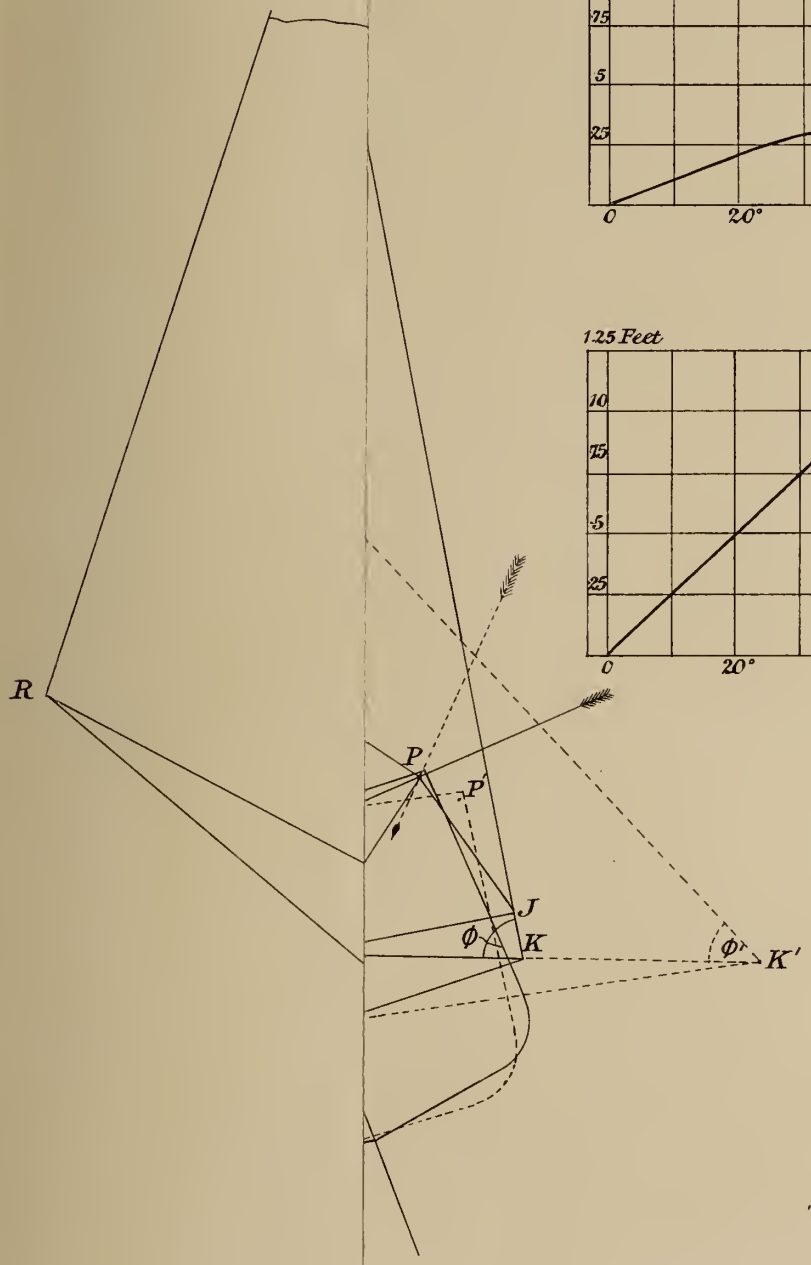


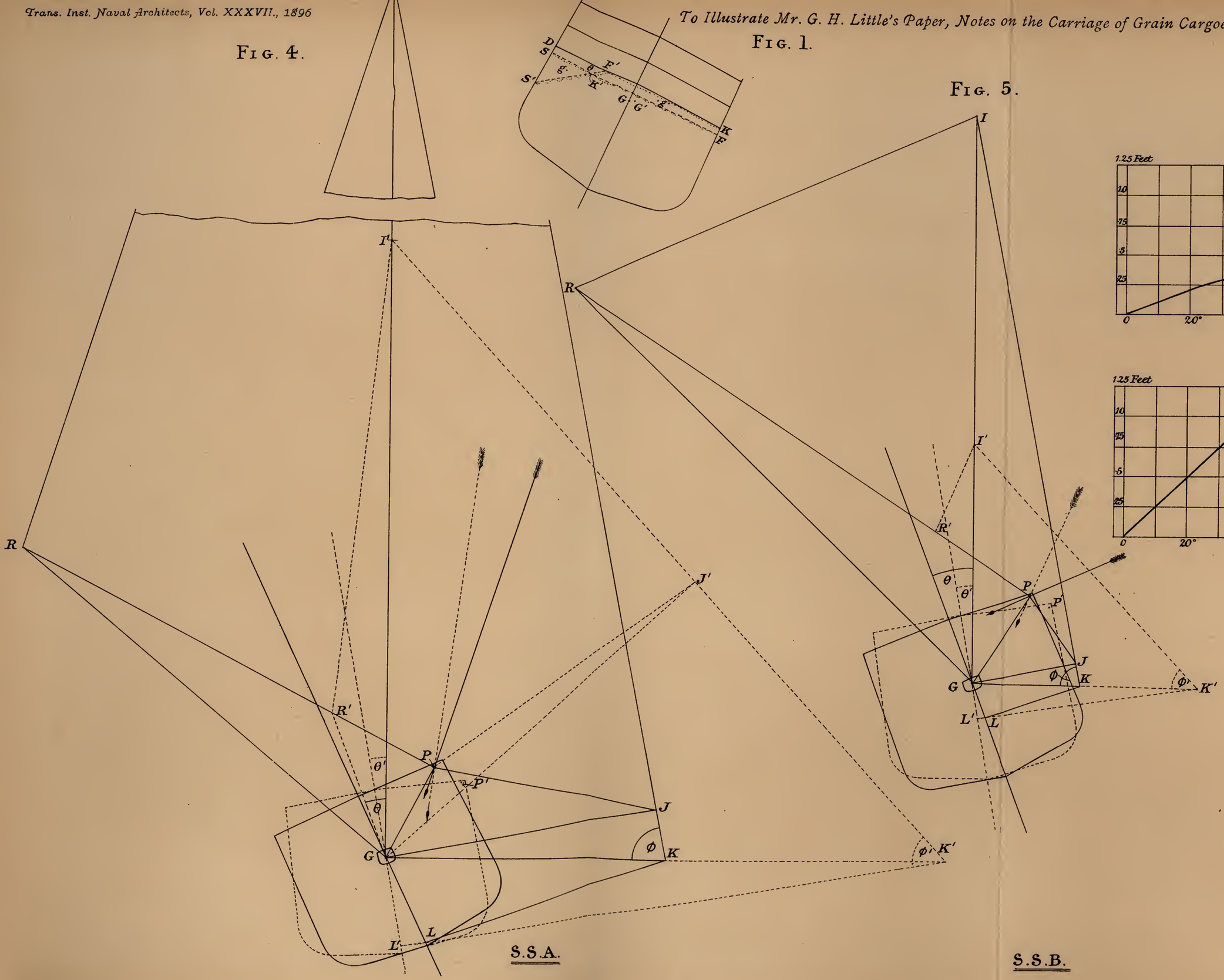
FIG. 3. S.S.B. G.M=1·5





S.S.B.

To Illustrate Mr. G. H. Little's Paper, Notes on the Carriage of Grain Cargoes.



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